

E-20-608
1

**PRELIMINARY RESEARCH ON PREFABRICATION,
PRE-ASSEMBLY, MODULARIZATION AND
OFF-SITE FABRICATION IN CONSTRUCTION**

by

Carl T. Haas
Walter R. Fagerlund

A Report to
The Construction Industry Institute
The University of Texas at Austin

Under the Guidance of
The PPMOF Research Team
PT 171

from
The Department of Civil Engineering
University of Texas at Austin
Austin, Texas

July 2002

Preliminary Research on Prefabrication, Pre-assembly, Modularization, and Off-site Fabrication in Construction

Executive Summary

Recent advances in design and information technologies, combined with increasing emphasis within the industry to address cost, schedule and labor issues, have proven the use of prefabrication, preassembly and modularization to be more viable than ever. Key factors influencing the decision-making on use of prework, including new technologies and a changing construction environment, have also expanded and changed. Successful implementation of prework requires a systematic analysis and decision-making process to evaluate the potential benefits and barriers to using these methods on projects.

The research team extended prior CII research efforts, identified state-of-the art practices of prework, and developed a decision framework to assist project teams in considering possible use of prework on their projects. In developing the decision framework, the research team focused on identifying the requirements for effective use of prework on industrial projects. The preliminary research presented in this report has been continued to further structure the framework and develop it into a computerized tool.

Pework is not for every project, but it can bring major performance improvements for the right ones. Using the framework described in this report, the construction industry can apply the experience of many seasoned prework users to its projects and if the project fits, the industry can realize the benefits from use of prework.

Preliminary Research on Prefabrication, Pre-assembly, Modularization, and Off-site Fabrication in Construction

Table of Contents

	Page
Executive Summary	i
List of Tables.....	v
List of Figures	vi
Chapter 1: Introduction	1
Overview	1
Objective	3
Scope	3
Methodology	3
Chapter 2: Background.....	4
Drivers and Benefits.....	7
Impediments.....	10
Chapter 3: Methodology.....	16
Overview	16
Literature Review.....	17
Identification of leading Companies for Case Studies.....	18
Interview Guide Development	18
Site visits and Data collection	18
Triangulation and Verification of Data	19
Decision Framework Development.....	19
Chapter 4: Data Collected	20
Overview	20
Central Texas Ironworks	21

Eli Lilly Co. Inc.....	22
McAbee Construction, Inc.	23
US Steel.....	25
BE&K.....	26
Jacobs Applied Technology	27
ProQuip	28
Prosser	30
Fluor Daniel.....	31
Howe-Baker	33
Summary	34
Chapter 5: Decision Frameworks.....	40
Overview	40
Decision Framework Timing Map	42
Strategic Framework: Level I.....	46
Strategic Framework: Level II	48
Pework Supporting Examples for Strategic Framework Level II.....	60
Tactical Framework.....	69
Interpretation of Framework Results.....	76
Triangulation and Verification of Data	77
Chapter 6: Conclusions and Recommendations.....	78
Conclusions	78
Recommendations	78
Appendix A: Site Visit Interview Guides	80
Owner Version	80
Engineering/Contractor Version	82
Supplier/Fabricator Version	85
Appendix B: Site Visit Reports.....	87
Central Texas Ironworks	87
Eli Lilly Co. Inc.....	91
US Steel Fairfield Works	97
McAbee Construction, Inc.	103

BE&K, Inc.....	109
Jacobs Applied Technology, Inc.	117
ProQuip Corporation.....	129
Fluor Daniel.....	139
Howe-Baker	147
References	154

List of Tables

Table	Page
2.1: Project parameters for feasibility of modularization (Deemer 1996)	6
3.1: Team member companies and institutions	16
4.1: Companies involved in data collection	20
4.2: Summary of Key Characteristics of the Prework Industry	34
4.3: Summary of Key Enabling Technologies	36
4.4: Characteristics of Companies Interviewed.....	39
5.1: Strategic Framework Level II Categories	47
5.2: Example of Case Option	68
5.3: Additional Costs Generally Associated with PPMOF	70
5.4: Cost Savings Generally Associated with PPMOF	70
5.5: Reasons for Productivity Improvement through PPMOF	71
5.6: Calculating Labor Cost for PPMOF Projects	72
5.7: Labor Risks and PPMOF Factors that Help Mitigate	73

List of Figures

Figure	Page
2.1: Pework use in construction (Eickmann 2000)	4
3.1: Flowchart of Research Methodology	17
5.1: Timing of Decision Frameworks.....	44
5.2: Strategic Framework Level I.....	46
5.3: Schedule Example from Strategic Framework Level II.....	48
5.4: Transportation Example from Strategic Framework Level II.....	48
5.5: Strategic Framework Level II.....	66
5.6: Breakdown of Tactical Framework Process.....	67
5.7: Breakdown of Tactical Framework Step #3.....	69
5.8: Schedule and Labor Hour Comparison	74

Chapter 1: Introduction

OVERVIEW

Prefabrication, pre-assembly, and modularization are strategies that have the potential to: (1) significantly reduce project duration, (2) improve productivity, (3) reduce labor needs and costs, and (4) have a positive impact on supply chain problems. Collectively known as prework, each is more or less applicable under specific conditions. Prework was found by a Construction Industry Institute (CII) Constructability Task Force to offer a substantial opportunity to improve project performance and overcome external and internal project challenges such as adverse site and local area conditions, lack of skilled labor, and demanding schedule, among others (Tatum et. al. 1987).

The successful application of these construction methods requires proper planning and decision-making processes. It is generally accepted that the tradeoffs for realizing the benefits of prework include project requirements such as increases in the amount of preplanning, engineering and coordination required for the project. The nature of prework tends to increase requirements for design and procurement logistics. In the past, companies have relied on expert knowledge, checklists, industry-wide tools or some combination therein to account for these requirements.

Given the fragmented nature of decision-making regarding prework coupled with challenges faced by the industry, a clear need for a decision-making process has emerged. Because of new technologies and a changing construction environment, factors influencing the decision-making process have expanded and changed in the last decade. These changes result in the need to reevaluate the role of prework and how decisions are to be made regarding the level and scope of its implementation.

New technologies such as computer controlled fabrication equipment, 3D CAD, electronic transfer of data, and the internet have provided opportunities for advances in design efficiency and coordination. While these technologies may provide overall project benefits regardless of the construction method, certain prework impediments can be directly reduced through the use of these information technologies.

Recent trends in construction emphasize smaller scale assemblies that exploit the capabilities of 3D CAD technology to ensure accuracy, precision, and visualization. In a Center for Construction Industry Studies at the University of Texas study, it has been estimated that the use of prefabrication and pre-assembly has increased approximately 90% over the last fifteen years (Eickmann 1999). The study was based on an extensive survey of over 27 construction professionals with a combined experience of over 700 years.

Other recent influences of information technology include advances in supply chain management. Information technologies have the potential to allow transmission of a “just-in-time” order for a rebar assembly to a fabrication plant and have that plant deliver the assembly within 24 hours, from scrap metal to final assembly and delivery. More common industrial applications include structural assemblies, piping spools, wiring harnesses, and pre-cast concrete modules. While this is an ambitious idea, it is now technically feasible. The capability and beneficial use of information technology on design and construction projects is advancing rapidly. The resulting ability to develop CAD models that include knowledge required for use of prework along with extensive engineering, procurement, and construction information about all the components of a plant is a major advantage for the potential use of modularization and pre-assembly. By its nature, prework contains more physical and organizational interfaces, providing opportunities for improvement through the automation made possible with CAD and other information technologies.

Changes in the current construction industry climate also align well with the concepts of prework, further justifying the updated frameworks reflecting these changes. The current shortage of adequate labor and skills can potentially be handled to a certain extent by prework. Increasing owner emphasis on safety, cost and schedule control for projects can also be potentially addressed by prework.

Adequate decision-making with regard to prework will require the inclusion of these technologies, as well as industry climate impacts and all influencing factors driving or impeding implementation. While some companies have employed prework methods successfully, the overall industry culture still has not fully recognized the potential for project improvements. Beginning with a set of comprehensive decision frameworks developed through the analysis of the methods already employed, dissemination of such a

tool through CII's consortium of owners, designers and contractors could provide the influence on the industry needed to establish prework as a best practice.

OBJECTIVE

The main objective of the research is to develop guidelines and frameworks for determining the level and scope of prework on a construction project. In support of this main objective, the research will also seek out the state-of-the art in prework decision making based on factors collected through literature reviews, interviews with leading companies, and insight from experts in the industry. More specifically, these factors include subjective and quantifiable project drivers, benefits and impediments to the use of prework.

SCOPE

The research covers the decision-making processes for the use of prefabrication, pre-assembly and modularization for industrial construction practices throughout the world. These processes include industry tools, checklists and planning methods. Project owners, suppliers, fabricators, engineers, and/or contractors may carry out these practices.

METHODOLOGY

The research methodology begins with a literature review of the past practices regarding prework for industrial construction. The research team then reviews the information to date and prepares for data collection regarding current practices. This preparation includes the identification of leading companies in the industry and the development of a questionnaire to collect the appropriate data. The team next conducts site visits to the leading companies and summarizes the data into trip reports.

Once the data has been collected, the team reviews the information and begins to structure guidelines and frameworks for prework decisions. Based on the team's expert judgment, data is filtered and combined to develop the framework structures. Upon completion of the frameworks, the team then will present the products for beta testing and eventually use in the construction industry. In addition, full documentation of the data will be archived for dissemination into the general body of knowledge.

Chapter 2: Background

Past research has identified that the use of prework has the potential to positively impact the construction process. Through studies conducted by CII, academic institutions and individual company cases, the drivers, benefits, impediments and the effects of these factors on decision-making for prework have been well documented in the literature. Further improvement of decision-making process for determining scope of prework for projects has only begun to be explored. The following chapter outlines the current knowledge regarding decision making, as well as the drivers, benefits, and impediments that support the process.

While the concept of prework projects can be traced back to Egyptian pyramids and Greek temples, the modern construction industry has only begun to take significant advantage of these construction processes in the past few decades. A recent study at the University of Texas revealed that the use of prefabrication has increased by approximately 86% in the last 15 years (Eickmann 2000). These activities can be found in many disciplines of construction, as shown in Figure 2.1. Prefabrication and preassembly was identified as existing to some extent in virtually every discipline. Major areas of prework included piping, structural assemblies and equipment.

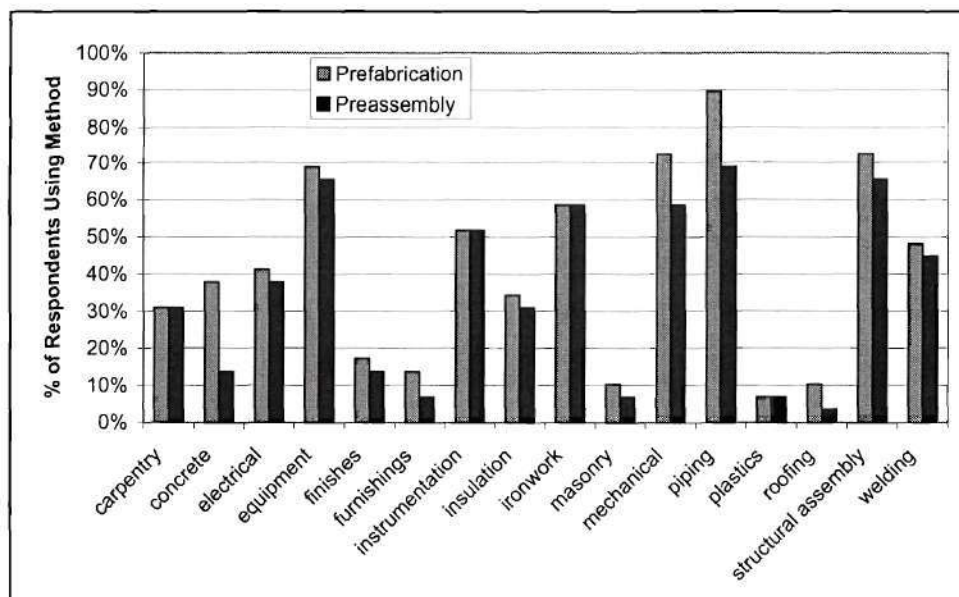


Figure 2.1: Pework use in construction (Eickmann 2000)

Appropriate timing and preliminary investigation also characterized successful decision-making regarding prework. The decision to use prework should be done early in the project planning. One drawback to this early requirement is the fact that the scope of the project must be well defined, as the design and transport of the assemblies will be based on set sizes and quantities. This reduction in flexibility can be an unattractive part of the project to the owner. Project scope can be altered, but usually at a higher than average premium and can easily negate the schedule and cost benefits that would have been realized. For these reasons, the decision the use prework may be most appropriate when made as early in the project as possible. Preliminary investigation involves the careful qualitative and/or quantitative analyses of the drivers, benefits and impediments are traditional methods for the prework decision process. While the timing of the decision is critical, the decision must also be made with the proper level of information (Tatum et.al. 1987).

As a result of the insight gained from the CII study in the late 1980's, a modularization decision-making software tool called MODEX was developed. The software, also called Modularization Expert, was created to enable project teams to evaluate the feasibility of using modularization for industrial construction projects. Incorporating important factors identified by the research team into its expert system architecture, the software provided three levels of feasibility analysis for the user. These included prescreening, detailed feasibility, and economic analysis. The prescreening process was a quick evaluation requiring minimal information to determine the general potential for modularization. If the project is determined to have a certain potential, the program proceeds with the detailed feasibility study and economic analysis. Project attributes for this section include plant location, environmental factors, organization, plant characteristics, project risk, and labor conditions (CII 1992).

Later studies validated the use of MODEX through testing with project data. The choice of developing the software as an expert system was deemed appropriate given the ease of use of expert systems, the ability to handle uncertainty, and the system's suitability for real world problems (Murtaza et.al. 1993). Even later work identified MODEX as a best practice in the decision making process for modularization in industrial construction (Mulva 1996).

Other software was also produced using the data collected by the CII task force. Beyond the expert system of MODEX, some research was conducted into the use of neural networks and multimedia technology to assist in the decision making process. One program used a multilayered, self-organizing neural network along with data from the CII research to determine the level of modularization to be used in a project. The system was found to be 80% accurate when tested with data from ten projects. The initial results concluded that the neural networks could produce the necessary accuracy for decision making (Murtaza 1994).

Another system incorporated multimedia technology with the project data from the CII task force. The Multimedia Decision Support System (MDSS), combined project data with the MODEX system. The system consists of four modules. Module one includes criteria for decision making and weighting factors. The second module contains the database of project information for the project in question. The third module includes a graphical database, with pictures and images regarding project information such as site conditions and transportation routing. The fourth module takes the previous three modules into account and uses a group decision-making algorithm help determine a solution (Vanegas 1995).

Beyond the work by CII and the subsequent following research, other sources have identified decision factors for prework. Providers of prework, such as companies specializing in modularization, have identified decision factors in industry journals and through marketing efforts. One major modular provider identified the factors in Table 2.1 when considering the use of modularization. Each area under consideration contains quantifiable costs and benefits.

Table 2.1: Project parameters for feasibility of modularization (Deemer 1996)

• Overall Cost	• Detailed design
• Schedule	• Procurement
• Safety	• Fabrication
• Operability and maintenance	• Transportation
• Quality	• Construction
• Impact on the local environment	• Secrecy
• Marketability	

From these projects, academic researchers and industry professionals alike have been able to identify the drivers, benefits, and impediments on the use of prework. These aspects all affect the decision making process and are the understanding of their impact is necessary for adequately determining the scope of prework. One limitation of these products was that many of them were based on expert system theory. Products such as MODEX and others attempted to collect and integrate all the knowledge available at the time to develop a single solution to determining prework application and level. Additional enabling technologies and project factors have altered the requirements and possible solutions for implementing prework. Technologies such as the internet, 3D CAD and digital imaging did not exist as widespread during this earlier research. Project factors have also changed as a result of a changing market and newer technologies. Market conditions have dictated newer products from facilities such as increases in the pharmaceutical and biomedical fields. Other factors such as labor issues, cost constraint emphases and other economic factors have also further shaped the industry in ways that may have been difficult to predict in the previous research. Therefore, the research proposed within this report will work to integrate the newer technologies and project factors while still allowing for future flexibility should additional consideration be required.

DRIVERS AND BENEFITS

Drivers and benefits for prework are often closely related and play a critical role in determining feasibility. Many drivers and benefits for the use of prework have been recognized, but they often vary with the type of prework under consideration. In general, modularization has been driven by project or site constraints such as harsh weather conditions. Preassembly and prefabrication are typically driven by cost and schedule issues. For example, pipe spools may be more economically prefabricated in a dedicated pipe shop location.

The traditional project factors driving desired benefits also apply prominently when considering prework. Cost, schedule, quality and safety are main drivers. Subcategories supporting these themes include productivity, risk reduction and environmental factors. Prework has the potential to positive affect the project in each of these areas (Gibb 1999). The reduced cost of fabricator labor compared to on-site workers combined with the

increased productivity of the manufacturing facility translates into schedule compression with minimal cost impact (Tatum et.al. 1987). Lack of availability of skilled, on-site labor may also play a factor into the decision to use prework. Shortages of skilled labor could be a strong driving force (Murtasa et.al. 1993).

Cost

Cost savings mostly consist of the differences between fieldwork and shop fabrication productivity and support costs. Other savings may be associated with overhead reduction, transportation and installation efficiencies and future projects. A CII study of industrial construction projects found that in some cases, estimates in cost reduction were 10% for overall project cost and 25% for onsite labor costs (Tatum et.al. 1987). Cost reductions were attributed to the lower cost of offsite labor. Shop productivity is often better than field because of controlled conditions, closer supervision, and easier access to tools. Controlled conditions such as ground level work, climate control and consistent lighting directly impact productivity. Given the closer proximity of workers and workspaces, supervision requirements and time to access necessary tools decreases in the shop. Often in the field the supervisor or the worker in need of a tool must cover large distances to accomplish tasks. In addition to productivity cost savings, prework can decrease costs associated with fieldwork.

Since some or all of the work is relocated to an offsite location, costs associated with site infrastructure and overhead can be reduced. Fewer workers on site translate into fewer costs for accommodations in remote locations, scheduling onsite work, and other onsite logistics. Other cost savings may include savings from fewer material deliveries and reduced crane usage. The cost of transporting a large assembled unit may provide savings over many shipments of individual pieces, including tracking and storage costs.

Future requirements for expansion or conversion of capital facilities may benefit from the use of prework on existing projects. Some prework can be designed to for expansion or relocation. For example, modular units may be designed for replacement or expansion depending on market conditions. Prework designs may also provide opportunities for replication, reducing costs associated with learning curves and engineering.

Some less quantifiable cost savings that are apparent include environmental impacts. Relocation of work offsite potentially reduces impacts to the field site. Reduction in infrastructure, influxes of construction workers and economic disruptions to the local communities may be reduced by prework (Deemer 1996). Additionally, work offsite may reduce material waste, pollution associated with dust and noise and overall energy costs (Gibb 1999).

Schedule

Schedule often drives the use of many forms of prework. Considerations such as outage requirements or market conditions may dictate schedule as a driver. Increased productivity and activity desequencing are typical ways of improving schedule with prework. By relocating work to off site locations with higher productivity, schedule savings are possible. One study in the area of building construction estimated a reduction in onsite labor of 40-50%, along with compressed schedules due to shorter critical paths (Warszawski 1990). Industrial construction has recognized similar benefits. For example, nuclear reactors designed using modular methods and off site fabrication have seen improvements in schedule length and control (Kupitz and Goodjohn 1991). Desequencing examples may include fabricating structural steel offsite while foundations are poured onsite. Desequencing may also be appropriate when permitting delays onsite work. Fabrication may continue offsite while permitting delays activities at the project location.

Other schedule benefits associated with prework include risk management. While prework provides opportunities to compress schedule, some of the most attractive drivers are improvements in schedule control. Off site work schedules by nature contain fewer inherent risks due to conflicting crews, weather delays or interferences with ongoing operations.

Quality

Pework may be driven by quality requirements. Fabricating components away from the site also allows higher quality control due to the controlled manufacturing facilities in which the components are constructed. Pipe racks that were once assembled on-site were subject to the weather and took up space on-site for assembly. Prefabricated

racks can be assembled in a fabricating facility under controlled conditions and then shipped to the project site.

Quality increases due to the controlled conditions under which construction is accomplished. For example, a structural steel assembly for a petroleum refinery that was once constructed over a hundred feet in the air can now be fabricated at ground level, in a controlled environment. The assembly can later be hoisted as a whole into place requiring only a few connections.

Safety

With prework, workers face less exposure and companies receive more opportunities for decreasing safety risk. Prework may reduce exposure to weather, heights, hazardous operations and neighboring construction activities. Workers indoors at a fabrication shop are not affected as much by temperature, wind and precipitation extremes. Since much of the prework is done at grade level, fewer safety harnesses are required and workers can focus more on the work. Less workers onsite also translates into reduced craft congestion and exposure to ongoing operations.

IMPEDIMENTS

While the drivers for prework help to determine the use of prework as an option, the decision to implement is influenced by the balance between the potential benefits and impediments. Common challenges faced by projects include increased engineering requirements, increased transportation considerations and decreased flexibility of scope. Other impediments can be grouped into site constraints, along with coordination, communication and organizational requirements.

Engineering

Case studies have estimated that engineering costs can increase as much as 15% and home office costs 5-15% per unit of prework. Depending on the extent of prework, it may be necessary to complete 90% of engineering design prior to construction, as opposed to the 40% generally necessary for conventionally built projects (Tatum et.al. 1987). Complex modular assemblies may require greater completion of engineering prior to

assembly due to complexity of interfaces and shipping envelopes. Interface management and transportation requirements may not only increase degree of completion requirements, but also account for a large portion of the estimated 15% increase in design.

Physical interface management requires further engineering to assure compliance between fabricated assemblies. Since components are fabricated in the shop and shipped to the installation location, additional engineering is required to insure compliance. Interfaces may include the connection between a pipe rack and equipment such as compressors or vessels. Other examples might include the connection between different floors on a stair tower or the connections between several structural steel preassemblies. If the assemblies are connecting to a foundation poured on the site, careful monitoring of the as built bolt locations and the final fabrication of the mounting angles to assure compliance during erection.

Design dimensions and loading may be dictated by transportation limitations. For example, the size of a large module for a power plant may be constrained by the lift capacity of a crane or the load capacity of a wheeled vehicle. The size of structural steel members of the module may be designed for peak loads experienced during the transportation or lifting process. These factors are examples of why engineering requirements and transportation considerations are increased.

Transportation

Transportation logistics play a large role in determining prework feasibility. Size and weight limitations, route restrictions, permitting and the availability of lifting equipment are among the considerations to be made for the coordination of construction. Size and weight may vary depending on the delivery method. Roadways, railroads and water transport all have limitations. The availability of these methods may dictate the type of prework selected. Water access may allow large modular units, while limited road access may constrain prework to smaller preassemblies or prefabricated components.

Methods of delivery may not only be dictated by access at the fabrication site and the project, but also by the routes to and from. Routes must be able to handle loads and the necessary permitting acquired. Once the components reach the site, additional lift planning may be required, especially for heavier lifts. While the number of lifts may be reduced, the

complexity of each lift generally increases with the increase in level of prework. Key considerations for heavy lifting include lifting points, rigging and early involvement of the lift contractor (Gibb 1999). Other factors include impacts on construction schedule, site design, as well as consideration for crane cost, availability and the cost of designing the plan itself. As trends in the industry move towards greater use of prework, heavy lift planning needs will increase also (Hornaday 1992). The impact of additional lifting requirements must be factored when determining prework feasibility.

Contracts and engineering may also be affected by increased transportation requirements. It may be necessary to secure transportation contracts prior to design completion (Stubb and Emes 1990). In some cases, the engineer may be required to design at risk, with calculations and drawings being completed prior to transportation permitting (Smock 1992).

Flexibility

Scope flexibility may decrease, especially with the use of modularization, since their use requires a well-defined scope early in the project planning stages. This is due to the increased engineering and transportation requirements. The scope must be set early to insure adequate design and integration upon construction and final assembly.

Site Constraints

Other factors affecting the use of prework include the local economy. In areas where the cost of labor is low, prework may not provide an economic advantage. Another concern is the knowledge base of designers concerning prework components. Engineers may not have experience with such construction projects and therefore prefer traditional methods. In addition, some specific areas of modularization, such as home building, may fluctuate with the market demand (Warzsawski 1990). This could translate to industrial construction for industries experiencing increased market demand in locations with energy shortages. One example in the power industry has been the modularization of new power plants to compress the construction schedule with cost savings associated with earlier time to market. One power plant contractor was able to reduce schedule by 40% by using

modularization to build 150 and 450 MW power plants. While construction costs grew from 0.5-2.7%, the total plant investment savings ranged from 12-15% (Smock 1992).

Coordination

Once the decision to use prework has been made, it is necessary to understand the extensive coordination required prior to and during construction operations. Coordination of design, transportation, tracking, and installation are critical components for successful implementation. This section outlines the project specific coordination needs as relating to prework in construction. The organization of those people involved in the process will be discussed further in the next section.

In addition to the transportation and design issues discussed, adjustments in the work breakdown structure, terminology, drawings, progress measurement, and scheduling may also have to be coordinated. Rather than systems, the work breakdown structure will deal with units. These units or modules may require new terminology for referencing drawings and schedules. Interface drawings may be required in addition to traditional plans. Progress measurement may also be in units rather than systems. The installation process may affect schedule considerations such as the critical path (Tatum et.al. 1987).

Further coordination may be required for materials management and supply chain scheduling. The complexity of assemblies, integration, and delivery provide opportunities for computer control (Stubb and Emes 1990). Standardization of these processes could help to further reduce the overall cost and schedule (Smock 1992).

Communication

Given the increases in coordination for projects utilizing prework, effective communication is necessary. Effective communication between project participants includes distribution of information regarding decisions, designs, transportation requirements, and schedules. In order to coordinate between multiple sites with critical scheduling, open communication must exist between owners, engineers, suppliers and contractors.

Organization

The roles of different project participants are affected by the use of prefabrication, preassembly and modularization. The relationships between owners, engineers, contractors, and suppliers are important to the success of the project. Just as the specifics of the project must be coordinated, so must be the people involved. The number, level of involvement, and contract requirements may vary compared to conventional methods.

Generally, the role of the design firm and the contractor is reduced. While the engineering design required increases, much of the work is transferred to the supplier or offsite fabricator. This results in decreased fieldwork and activity at the actual jobsite. The contractor's role is reduced by the decrease in manpower size and duration in the field. The one design discipline whose role may increase is the structural design firm or department, given the complexity of the lifting and transportation requirements. The role of the supplier increases, and in some cases the supplier works directly with the owner. This can bypass the design firm and contractor, further reducing their involvement (Tatum et.al. 1987). Management requirements for the project will increase, since a strong client presence may be required at the fabricator to maintain cost, schedule, and quality control (Stubb and Emes 1990). Regardless of the amount of work shifted throughout the project organization, early participation and effective communication are keys to success.

While the roles of project participants changes with the use of pre-assembly and modularization, the complexity of procurement increases. The use of multiple sites for the construction of components and modules adds to the increased need for proper organization. The contractor or fabricator handles the procurement in some cases. Regardless of who procures the materials, the responsible party needs to understand that some items may be required sooner than similar conventional projects. For example, instrument or control components traditionally installed near the end of the project may require procurement earlier for the installation into assemblies constructed prior to transport to the site. These offsite projects become "mini-projects", with their own project management staff and quality control (Tatum et.al. 1987). For these reasons, procurement complexity increases organizational requirements.

In addition to changes in organizational requirements for participants and procurement, project contracting may also be influenced by the use of prework. Generally,

knowledge and influence shifts from the general contractor to the subcontractor or fabricator. Since the subcontractor or fabricator has greater knowledge or in some cases, proprietary knowledge regarding assemblies, they possess a higher profit potential compared to conventional methods. Traditionally, construction down on site was familiar to the general contractor and unit cost driven. With some prework done offsite, the subcontractor has greater control of pricing and maximization of benefits. In some of these cases, it may be beneficial for the general contractor to integrate the subcontractor into its organization. Ideally, the general contractor may benefit from owning the subcontractor (Hsieh 1997).

The type of contract to be used may also be a factor in the organization of the project. Different contracts have been used in the past, with variations depending on the risk assumed. In cases where risk is increased due to the use of new technologies, the contractor may assume the risk with a turnkey style contract. This requires a premium to cover the risk and may reduce cost savings related to pre-assembly and modularization. In order to maximize cost savings by eliminating the risk premium, owners may choose to assume the risk with a more traditional contract. In some cases, owners who have assumed the risk in a more traditional contract such as own-and-operate have realized savings on average of 15% over turnkey options. However, this requires a knowledgeable owner who is disciplined in the management of such projects (Smock 1992).

Overall, the organizational requirements for projects involving prework increases. This is reflected in the changing roles of project participants, increased complexity of procurement, and contracting issues.

Chapter 3: Methodology

OVERVIEW

Research was conducted as part of a project team for CII. The team consisted of representatives from the construction industry and academic institutions. Industry members represented ranged from owners to contractors to design firms, each involved in some way with prework. Academic members represented three institutions and each had prior experience researching prework. Table 3.1 lists the companies and institutions participating in the research. The overall project duration was slightly more than two years.

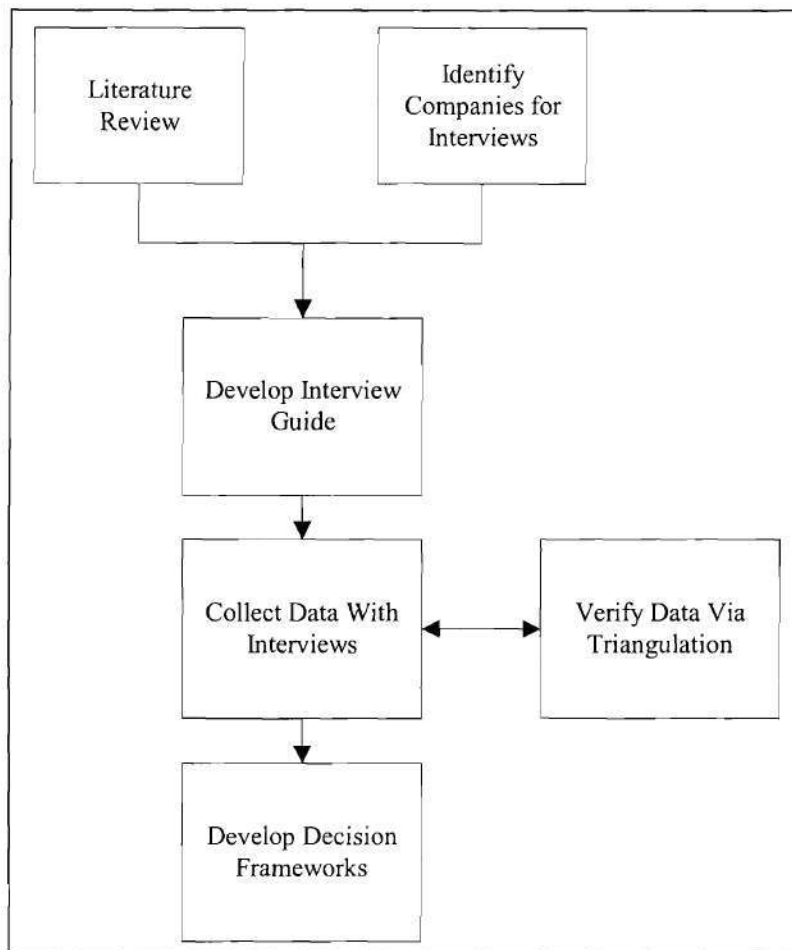
Table 3.1: Team member companies and institutions

• BE&K, Inc.	• Stone & Webster
• Chicago Bridge and Iron Company	• Stanford University
• Eli Lilly Company, Inc.	• The University of Texas at Austin
• Eichleay Engineers, Inc.	• U.S. Army Corps of Engineers
• Georgia Institute of Technology	• U.S. State Department
• Jacobs Applied Technology	• U.S. Steel
• Kvaerner Process	• Washington Group Int'l
• LTV Steel Company	

The methodology for the research follows several steps, shown in the flowchart in Figure 3.1. First, a thorough literature review was conducted to determine the work to date in the areas of prework as discussed in Chapter 2. Team members reviewed the past research and identified companies currently involved in industry-leading practices in the use of prework. Projects were identified for case studies and an interview guide was developed to collect state-of-the-art information. The case studies identified current decision-making processes and timing. The data was summarized initially in trip reports and was verified via triangulation with past research and the expert opinion of team

members. The data was integrated and submitted for dissemination into the industry as part of the products required of the team by CII.

Figure 3.1: Flowchart of Research Methodology



LITERATURE REVIEW

A literature review was conducted to determine the prior research and developments in the areas of prework, and information technologies. The literature included industry journals, conference proceedings, and past CII products. Databases were searched via access through the University of Texas library system.

IDENTIFICATION OF LEADING COMPANIES FOR CASE STUDIES

The project team held a meeting to review the current literature and to identify possible case studies. Given the wide range of industries and types of project participants represented, a broad list of owners, contractors, designers and vendors was generated. The team identified types of prework carried out by the companies and provided points of contact to set up the case studies.

INTERVIEW GUIDE DEVELOPMENT

An interview guide was developed for the case studies based on the literature review and the experience of the project team members. Separate guides were developed for different respondents in order to concentrate on specifics for each. Separate guides were developed for owners, engineer/contractors, and supplier/fabricators. Attempts were also made to remove bias in the questioning in order to assist with validation of results. The complete interview guides can be found in Appendix A.

SITE VISITS AND DATA COLLECTION

Site visits were conducted using the contacts identified and the site visit guide. Points of contact were reached based on the list generated by the team. Academic representatives of the project team usually conducted the interviews over a period of 1-2 days at the site of the case studies. Site visits included meetings at the company home offices, tours of fabrication shops, and walkthroughs of construction sites in progress. In some cases, companies provided examples of their own decision tools and information regarding past projects. The information was gathered into trip reports for documentation to be accessed later for product development. Additional information gathered also included company literature such as informational products including flyers, pamphlets, videos and official internet sites. Trip reports were presented to the respondents and to the project team members for review and verification of the accuracy of the information recorded.

TRIANGULATION AND VERIFICATION OF DATA

In order to determine validity of the data collected, the data from the site visits was analyzed via triangulation with past research and expert opinion. Survey results from past research by the University of Texas were compared to the data collected. Team members with experience in prework also confirmed data collected through the site visits.

DECISION FRAMEWORK DEVELOPMENT

Academic team members began the synthesis of the data by developing drafts of decision frameworks. The framework structures and data were developed based on the data collected. The data included the trip reports, literature review information, and existing decision tools used by companies to determine the use of prework. These drafts were presented to the project team for revision. The frameworks were then completed based on the team's input and included as one of the products for CII for dissemination throughout the construction industry.

Chapter 4: Data Collected

OVERVIEW

In order to provide the most recent and relevant data for the development of the proposed decision frameworks, site visits and interviews were conducted. Companies were chosen for data collection based on expert opinions of team members experienced in the use of prefabrication, preassembly and modularization. Data was collected from a variety of project participant types and focused primarily in the industrial sector, since the team was composed of mostly members involved in this type of construction. Project participant types included owners, designers, contractors and suppliers of prework. The goal of the sample size was not statistical relevance but a snapshot of the current state of the art in prework. Overall, companies selected were involved in a broad range of activities and typically larger industrial projects. Table 4.1 lists the companies involved in the data collection, as well as the type of project participant. This chapter is meant to be a summary of the data collected. A complete copy of the data collected can be found in the trip reports, located in Appendix B.

Table 4.1: Companies involved in data collection

Central Texas Ironworks	Supplier, structural steel products
Eli Lilly Co.	Owner, pharmaceutical products
McAbee Construction.	Supplier/contractor, industrial
US Steel	Owner, raw steel manufacturing
BE&K	Contractor/Engineer, industrial
Jacobs Applied Technology	Engineer/contractor/fabricator, industrial
ProQuip	Engineer/contractor/fabricator, industrial
Prosser	Engineer/contractor/fabricator, industrial
Fluor Daniel	Engineer/contractor, industrial
Howe-Baker	Engineer/contractor/fabricator, industrial

CENTRAL TEXAS IRONWORKS

Central Texas Ironworks (CTIW) mainly prefabricates steel structural and supporting components for large capital projects. Key features of the company's processes include the use of electronic transfer, bar coding, 3D CAD, database integration, partnerships with customers and plant layout efficiency. Each of these components contributes to the requirements of prework, mainly by addressing design and coordination concerns.

Since prework requires a larger amount of communication due to the need for earlier collaboration and coordination of multiple work locations, the use of information technologies has further enabled CTIW's fabrication of prefabricated components. Through the use of electronic file transfer capabilities, CTIW designers are able to receive structural designs via the internet to be used in detailed design of connections and components. Since design information is often needed earlier in the project life cycle for prefabrication, faster transfer of design data via internet helps facilitate the process. 3D CAD software enables faster detailing of drawings and development of shop drawings for the fabricators. Automatic generation of some shop drawings can be directly sent to an internal database for the computer-controlled fabrication, reducing turnaround and potential for reading errors.

The database containing the design information is linked to the materials management database and the company extranet. Certain materials receive bar codes during the fabrication process that are linked to the database. From the company extranet, customers have a controlled amount of access to component status in the database. Customers can coordinate project activities with the shop fabrication. To further aid in communication and coordination, CTIW promotes partnering with its customers. Partnering reduces redundant project processes and communication.

The layout of the facility also affects efficiency of the prefabrication process. In addition to the links with material databases and design information, the work areas are laid out to optimize fabrication. Work flows from raw material laydown areas to each sequential part of the fabrication process with minimized material handling. Each station is linked to the design database reducing the potential for fabrication error. The large fabrication equipment allows faster and more accurate construction of the components.

Contrasted with more conventional methods of field construction of components, the integration of fabrication and design helps to reduce rework potential and expedite construction.

The required increase in coordination and communication requirements relevant to prework is further facilitated by CTIW's use of information technologies, client relationships and fabrication area layout.

ELI LILLY CO. INC.

Eli Lilly is an owner of large capital facilities for the manufacture of pharmaceutical products and has been involved in the use of modularization techniques for the construction of some capital facilities. Some projects include plants for producing bulk chemicals and finishing facilities for manufacturing drug delivery products such as pills and capsules. Eli Lilly's business requirements and the nature of the pharmaceutical industry help to drive the use of prework techniques. Drivers include business needs, time to market issues, safety and risk reduction. Major impediments include internal company resistance to prework due to lack of experience with the techniques and tighter planning requirements. The company found that overcoming these impediments were accomplished by involving experienced designers and contractors, as well as more subjective decision making by company champions of prework rather than detailed decision analysis.

The business and nature of the pharmaceutical industry produce many factors that drive prework. Time to market can be a critical factor since the timing of product introduction to the market place can have impacts of revenue and market share. The ability to make later decisions regarding whether or not to go forward with a project is facilitated by prework through parallel and offsite activities. Shorter project life cycle translates into late decision-making capability. Additional benefits include the ability to delay projects for business reasons and decrease time to market. Lilly has been able to delay projects without extending completion dates, reallocate money to other projects while delaying construction and also provide opportunities to obtain more accurate design information. Decreased time to market also assists Lilly in delivering products as soon as regulatory approvals are issued.

Beyond business and industry specific drivers, safety and risk reduction are seen by Lilly as further reasons for implementing prework. It is believed that safety increases due to the increased amount of work done at ground level. Modular units for one finishing facility were constructed in units no taller than 14 feet. Safety risk is therefore reduced due to reduced exposure to high work. Other forms of risk reduction include reduced risk of building unnecessary projects or projects lacking useful longevity. By shortening the life cycle process, projects can be built later when market conditions are clearer. The use of modularization also promotes expansion and salvage capabilities when a facility reaches a point of inefficiency. For example, modular layouts can be designed to accept future expansion of production by adding modular units. Furthermore, components can be designed for easier replacement, removal or relocation when industry conditions dictate.

Key requirements for implementing prework and overcoming impediments primarily involve education of project participants and increasing planning for projects. Overcoming impediments such as cultural issues, transportation requirements and scheduling for long lead items were felt to be the keys to the success of modular projects. Cultural issues mainly included lack of experience or knowledge of modular construction by the company's engineering and construction staff. This was primarily overcome through high-level subjective decision-making regarding modularization and involvement of experienced designers and contractors. The project team identified additional planning requirements for transportation of modules and long lead items such as large equipment early in the project to overcome these impediments.

MCABEE CONSTRUCTION, INC.

McAbee Construction, Inc. is a supplier and contractor involved in prefabrication, preassembly and modularization of components for industrial construction projects. The company believes the main drivers for the decision to implement prework include labor and schedule requirements. The main obstacles identified include overcoming client and designer preconceptions about prework and handling the increased planning requirements and information transfer required on prework projects. Key methods for helping these impediments include the use of 3D CAD, extensive team building, and the electronic transfer of information.

The company identified labor issues and schedule requirements as main drivers for the use of prework. In project locations where skilled labor availability and productivity was lacking, part or most of a project can be relocated to a shop environment more conducive to project objectives. The company claims higher productivity in the shop compared to the field due to factory conditions and lower wage requirements. Factory conditions such as indoor work, lower working heights, more efficient tool and equipment layout, and proximity to support elements such as raw material and engineering are believed to promote increased productivity. In addition to labor issues driving prework, schedule considerations are seen as significant. Delays in permitting for projects, existing operations on site and market considerations are seen as some of the main schedule drivers for modular and other types of prework. Work can be completed offsite while permits are awaiting approval. Work onsite and impact to existing operations can be minimized by modularizing or preassembling large portions offsite. Components can be tested and verified at the shop location to minimize start up time after field installation.

The main impediments to prework include client and designer preconceptions and planning and information transfer requirements. It is the company's experience that many clients still have misconceptions regarding operability and maintainability of modular designs. Contrary to the cramped design of older modular skids, the company makes attempts to express the carefully laid out designs of newer modular and preassembled projects. This is primarily achieved through the use of 3D CAD models and examples of existing facilities built using prework. 3D CAD allows clients to "walk through" modular layouts before approving design or beginning construction. An additional impediment to the use of prework includes a required paradigm shift in thinking on the part of the designer. Many designers are typically not schooled in modular design and the art of layout for shipping envelopes. This impediment is typically overcome through team meetings and involving all parties in the design process.

Planning and information transfer requirements generally increase on projects involving prework. Increased preplanning and involvement of the owner, designer, contractors, operators and suppliers are keys to successful implementation. This coordination and planning is handled through a team-oriented approach. The team composed of the project participants has regular meetings at different stages of the project

design. Electronic data transfer and email is used to expedite communications, help reduce overhead and paperwork and increase documentation.

US STEEL

US Steel is a large owner company involved in the production steel sheeting and piping stock material for other industries. Capital facilities include large, equipment intensive industrial projects for manufacturing steel. The company has experience using modularization and preassembly for the construction of its facilities. These methods have been driven by goals of outage minimization, testing verification of equipment and risk reduction. Main impediments to the use of prework were identified as increases in preplanning and engineering. Prework is mainly used for equipment or assemblies to be installed during outages with heavy emphasis on pretesting and verification. Constructability reviews, electronic data transfer and partnering are primary methods of overcoming impediments.

The primary driver of the construction of new capital projects for steel production facilities and therefore the usage of prework is the minimization of outage of steel production. Whether the project is designed to upgrade to meet environmental regulations or increase production capacity, the project must minimally impact existing operations. Conversely, the construction process must be protected from safety risks associated with building near ongoing operations. To achieve these goals, many components of construction projects are prefabricated, preassembled or modularized. For example, if a new piece of production equipment is to be installed and it will require a shutdown of the existing facility, every effort is made to preassemble and test the components prior to installation. In addition to reducing the shutdown period and start up time, fieldwork and therefore exposure to hazardous operations is reduced.

Overcoming the impediments associated with prework is handled in several ways. Increased preplanning and engineering associated with prework is generally preferably handled through partnering. By partnering with the project participants, the team atmosphere helps to handle the increased planning and coordination required for prework. Planning transportation requirements and routes, coordinating design information with shutdown schedules and construction considerations are achieved through constructability

reviews. Email and electronic file transfer are used to reduce information request lead times and increase documentation.

BE&K

Handling both engineering and design of industrial projects, BE&K has experience with many types of prework. These mainly include prefabricated and preassembled structural and mechanical components. Some company managers have been involved in modularization in the past but the methods are not typically used currently. Main driving forces for the use of prework include safety, schedule requirements including outages and various labor issues. Major impediments to using prework include lack of industry experience, increased laydown space requirements and increased engineering costs. Key methods of overcoming impediments include contract incentives and improved design and information transfer technologies.

Safety, schedule and labor requirements represent the main drivers for prework use. The company and clients believe that the use of prework decreases safety risk due to reducing high level work. For example, construction of structural steel frames for chemical process facilities may be erected by floor at ground level and lifted into place upon completion. Other examples include prefabricated concrete columns, beams and wall structures built in a factory. Components arrive on site in sequence complete, reducing the need for high formwork or scaffolding. In general, moving work offsite or offplot has the potential to reduce exposure.

Schedule has also driven the use of prework. Outage constraints and time to market issues have required schedule compression and parallel work activities facilitated by prework. Parallel activities have been achieved through prework of structural components. Foundations and other civil work can be handled while prefabricated or preassembled activities occur in parallel. The result is schedule compression to meet the project objectives.

Labor issues play a role in the selection of prework methods. If the current industry or project area lacks adequate skilled labor, prework may provide opportunities to relocate work to areas with more skilled or productive workers. In some cases, increased safety

characteristics of prework have helped to attract and retain workers. For example, some workers prefer to work at ground level preassembling steel rather than high work.

In order to benefit from prework and satisfy driving forces, the company has identified experience issues, increased space and planning requirements as major impediments. Lack of industry experience with prework methods has provided challenges initially to the use of prework. Improved visualization through 3D CAD has helped to analyze prework options and convince clients that operability and maintenance will not be compromised by prework designs. These advances in design have also allowed engineers to reduce drawing rework and identify interferences prior to construction.

Space and information requirements pose challenges in addition to the experience issues. Projects utilizing on site preassembly require additional laydown space for the ground level work. One estimate for preassembling structural components required 50% additional site space in addition to the facility footprint. Other considerations include increased planning and engineering. Increased planning and coordination is facilitated through the use of electronic communication via email, project internet sites and electronic drawing transfer. These technologies have improved communication and coordination between multiple sites. Estimates for engineering increases range from 5-10% more for certain prework. For example, the steel preassemblies required additional design for component lifting rigs and center of gravity calculations.

JACOBS APPLIED TECHNOLOGY

Jacobs Applied Technology provides design and construction of prework solutions, mainly modularization, for the industrial process industry. The company has identified many drivers for using modularization ranging from business to project site-specific characteristics. Major business drivers include time to market, financial viability and technology protection. Primary project drivers include schedule, cost, site constraints, permitting and impacts on existing operations. Impediments to the use of prework mainly consist of transportation constraints and experience issues. Formal decision tools, integrated 3D CAD systems, computer communication technologies and company experience help to alleviate impediments and identify driving factors.

Drivers and impediments play a major role in the decision to implement modularization. The company uses subjective and uncomplicated decision methods to identify drivers early in the project during planning stages. After inquiring about general project drivers such as schedule, safety and labor conditions, possible constraints including transportation limitations and equipment size are identified. Through this decision process and the use of expert judgment, levels of prework for a project are determined. In many cases, one issue can emerge as a primary driver or impediment of modularization. For example, a site located in a remote and harsh environment may dictate the use of modularization regardless of other factors such as schedule and transportation requirements. Conversely, a site lacking transportation access or is too costly to upgrade local routes may require more conventional construction. In either, modularization was dictated or excluded early in the project based on broad factors.

Once the decision to modularize has been made, 3D CAD and other computer technologies are used to overcome challenges involving increasing client awareness of modular layouts, as well as increased requirements for planning, coordination and engineering. The company uses 3D CAD to help clients visualize projects before construction. Design review meetings allow project participants to walk through projects to address concerns regarding constructability, operations and maintenance. Integration of material management information with the 3D model allows faster access to and coordination of project information. 3D CAD also expedites design by identifying interferences and reducing design and construction rework. Other computer technologies such as email, electronic file transfer and offices linked via intranet have helped facilitate the increased communication and coordination required of modularization projects.

PROQUIP

ProQuip is a turnkey provider of industrial process facilities. Prework consists mostly of modularized unit, with preassembled and prefabricated supporting elements. The company provides design, fabrication and installation. Main factors for implementing modularization include site conditions, labor rates, safety requirements and schedule requirements. The main obstacles to implementation are typically transportation requirements, coordination issues, labor unemployment and industry misconceptions

regarding modular design. Emphases on company organization and prior work experience have been ways to counter the impediments. By promoting efficiencies in organizational structure from concept to installation, the company has worked to improve the turnkey process. The company has also worked to alleviate misconceptions by showing perspective clients prior successes through site visits.

Site conditions, labor rates, safety requirements and schedule requirements were specified as the primary drivers. Site conditions may include limited plot space, remote location, and extreme weather. Congested plot spaces surrounded by existing operations or adjacent properties may provide opportunities for prework. Relocating work could reduce congestion and craft density on site. Remote locations lacking infrastructure for field operations may benefit from prework at more adequately supported location. Extreme weather may also drive prework, since elements such as extreme temperature or precipitation may hinder fieldwork.

In addition the site conditions, labor rates were particularly identified by the company as key. A major labor driver identified was the difference between labor in the fabrication shop versus equivalent work done in the field. Cost savings resulting from transferring hours to the shop may offset additional costs of coordination, engineering and transportation. Some company officials estimated that shop productivity could be 30-50% better than field with a 20-40% reduction in hours required to complete the work. The result could potentially include both cost and schedule reduction. In addition to shop labor driving prework via cost and schedule reduction, additional concerns such as adequate labor availability are also potentially addressed through prework. Relocating field hours to the shop may alleviate skilled labor shortage problems related tot the site location.

Safety and schedule requirements were also seen as major factors driving prework. By transferring hours offsite, prework may reduce craft density and total craft hours on site. Additionally, work offsite is typically conducted in a controlled climate, at ground level and away from ongoing operations that may present hazards. Schedule requirements may also be facilitated by the use of prework. Obtaining market share and time to market requirements have been factors influencing many prework projects.

Overcoming the impediments regarding industry misconceptions, transportation requirements, increased coordination requirements and labor unemployment have been

keys to prework implementation. Industry misconceptions were similar to the impediments identified in other interviews. The company found that many clients still view modular construction as cramped, difficult to maintain, expense to ship and difficult to install. The company primarily uses past experience and site visits to successful projects to demonstrate accessibility, maintainability and feasibility of modular designs. While the company is moving towards 3D CAD to among other reasons improve customer visualization, the company has been satisfied with site visits and case studies to promote their work.

Transportation and coordination requirements have typically been handled through the company's experience and through organizing overall structure to facilitate turnkey projects. Transportation limitations may be dictated by accessibility to the site. For example, barge access would allow larger prework assemblies such as large modules and preassemblies. Road access only would require smaller prework units. Any additional costs associated with access would have to be weighed against the benefits.

The company has addressed increased requirements for engineering, coordination and communication by improving company organization. This organization takes place at different levels, from organization of disciplines to fabrication shop layout. Sales and engineering offices are integrated into the same office, with fabrication facilities nearby within the same city. Engineering tools and fabrication equipment efficiencies are stressed over high technology. For example, 2D CAD has proven sufficient for design. Fabrication equipment, while older technologies prevail, efficiency is maintained through precise layout and skilled craft workers.

PROSSER

Prosser is involved in the modular design and construction of chemical process facilities. While a site visit was not applicable at the time of the study, information was provided via a company promotional video and a company website. Benefits associated with modularization were consistent with other modular providers. These benefits included reduced safety risk due to indoor, ground level work; schedule compression due to parallel activities, higher productivity, and reduced risk; and cost savings associated with labor factors.

The company outlined a basic decision tool called the “Modular Analysis Program.” The tool covered questions regarding site conditions, labor issues, transportation access, equipment type and other factors. All factors were considered drivers or impediments to implementing modularization. Each question was ranked according to how it influenced the applicability of modularization. For example, a site with poor weather conditions may score high on the survey for modularization. Conversely, a site with very limited access may score low. A final score is given with a range for varying degrees of opportunity, as well as breakdowns of areas such as labor and site conditions.

The company also worked with a large contractor to develop conceptual cost comparisons of modularization versus conventional methods. Differentials between projects included labor cost and productivity rates, engineering costs and transportation costs. Labor cost and productivity rates were a primary driver, with high cost and lower productivity rates of field labor driving the work towards modular construction.

FLUOR DANIEL

Fluor Daniel is a large designer and contractor involved in industrial construction. The company employs prefabrication, preassembly and modularization on many projects. The use of modularization is often decided early during project preplanning and is primarily driven by project and site conditions. Preassembly and prefabrication are mainly considered later during detailed design or construction. These forms of prework are primarily cost issues. Impediments to either of the prework types include obstacles to transportation, increased planning and coordination, site laydown area requirements, and site/contract constraints.

Site conditions and project drivers mainly drive modularization. Remote locations and extreme weather were typical rationale for modular work. For projects involving modularization, decisions to implement modular are typically made early in the project during conceptual design. For project participants unfamiliar with modular issues, the company holds a brief seminar on the benefits, impediments and considerations to be made. Past modular example are presented to highlight individual points. This helps to educate participants and facilitate a team atmosphere, helping to overcome impediments regarding experience, communication and coordination issues early in the project.

Once the decision to use modularization is initially made, the EPC team develops a cost and schedule comparison to conventional methods to determine more precise feasibility. The cost estimate determines costs removed from the site, as well as additional direct and indirect costs. Cost removed from the site may include field hours and engineering design hours moved to the shop. Additional direct costs may include additional engineering required, transportation costs and any added fees or duties. For indirect additions, items may include increases in office staffing to handle expediting or permitting. From these three categories, a cost delta is developed to determine feasibility.

Schedule impacts resulting from modularization are also analyzed as part of the decision process. Impacts resulting from parallel activities, productivity differences between shop and field, and the effects of altering craft density are all taken into account. The result is compared to conventional methods to aid the decision.

For other prework methods, such as prefabrication and preassembly, the decision to implement is typically made later in the project and more from a pure cost analysis. It is the company's experience that while modularization is driven by project and site factors, prefabrication and preassembly are dictated by cost. Where decisions for modularization may involve broader scope and education of the client, other prework method decisions are more straightforward.

In order to handle the increased engineering, communication and coordination issues related to all forms of prework, the company has incorporated advanced computer technologies. 3D CAD, bar coding of materials, 24-hour engineering and electronic transfer of information have all been incorporated. 3D CAD is heavily used on projects to identify interferences and improve project visualization. Bar coding of materials has helped to manage, track and identify components. Since offsite work increases the amount of tracking and transportation needs, bar coding assists with the management of materials and equipment. The use of 24-hour engineering with global engineering offices and electronic file transfer, increases in engineering, communication and coordination can be handled.

HOWE-BAKER

Howe-Baker Engineers Inc. is a firm involved in the design and construction of facilities for the industrial process industry. Modularization makes up approximately 50% of the work with preassembly and prefabrication throughout projects. Key drivers are typically site conditions, labor issues, project type and safety concerns. Site conditions include weather risks, ongoing operations and access. Labor issues typically include lack of adequate labor, high cost of field labor and organized labor considerations. Project type may drive prework if involving congested piping or equipment, unusual alloys or increased amounts of high-level work. The later also addresses safety considerations in what the company's sees as an increasing safety culture in construction.

Impediments to the use of modularization include client awareness, as well as increased engineering, coordination and transportation costs. The company works to increase client awareness of modular design efficiencies by producing successful projects in the form of case studies or site visits. While the company has the capability to use 3D CAD for these purposes, they do not feel it is cost effective. 3D CAD is used however to improve the engineering process. Complex piping and electrical systems generally associated with modular work can be more easily designed in 3D. Interference checking and visualization of complex areas are both better facilitated with 3D as opposed to 2D design.

Overcoming impediments related to engineering, coordination and transportation are seen as key to modular success. Modular design often requires additional steel to reinforce modules during fabrication, transport and erection. Since over designing reinforcement may negate cost benefits, structural engineers work closely with other disciplines to optimize design. This coordination takes place in the form of in-house interdisciplinary collaboration meetings held several times during the design process. Additionally, disciplines work in close proximity to each other to facilitate increased communication. Impediments associated with transportation issues are handled by a dedicated expediting staff. These people handle routing, permitting and other considerations specific to transportation of prework.

The decision to use modularization or other forms of prework is typically handled by staff early in the project. Rather than a formal procedure, flowchart or checklist, the company bases decisions on the experiences of seasoned staff members.

SUMMARY

Many common themes emerge from the information collected in the site visits. The data collected identified many key characteristics common to the prework industry, shown in Table 4.2.

Table 4.2: Summary of Key Characteristics of the Pework Industry

<ul style="list-style-type: none">• Careful selection of prework is part of a spectrum• Pework complexity determines decision timing• Pework generally requires:<ul style="list-style-type: none">• Earlier decision making• Integrated involvement of project participants• Detailed analysis of labor differentials• Overcoming lack of industry knowledge• Detailed transportation planning and expediting• Thorough shop testing and verification• Careful supply chain management
--

Careful selection of prework is part of a spectrum rather than all or nothing. More recently, companies involved in prework have worked to emphasize that the question regarding use of prework is not, “To use or not to use,” but rather, “How much should be used to maximize benefit?” Pework should be deliberately applied to areas of a project and not applied across the board as a percentage of work.

Pework complexity generally determines decision timing. Timely, informed decision making about prework can payback the investment in the time it takes to make the decisions. Each of the companies involved in full modularization stressed the importance of early decisions during pre-planning when using high degrees of prework. In cases with a lesser degree of prework, such as prefabrication used by BE&K and Fluor Daniel, decisions could often be delayed until later in the project during detailed design.

Regardless of the type of prework, every company stressed the importance of coordination of all involved parties. For example, Howe-Baker stressed this coordination through regular meetings between various design disciplines to coordinate interfaces and routing of various components.

Careful analysis of labor differentials was a common factor in determining prework feasibility. Moving work off-site takes advantage of lower wages available in shops and potentially lower costs related to equipment and overhead. Each of the companies carefully evaluated the differences in wage rates, productivity, overall risks, equipment and overhead costs associated with labor. Companies also used prework to address the skilled workforce shortage by replacing mobile, site based, skilled labor with less skilled, but steadier shop based labor which is easier to access for projects.

Overcoming lack of industry knowledge was seen as another key factor in successful use of prework. Many providers of prework convinced less educated project participants that the latest prework could be designed to address maintenance and operation requirements better than the cramped skids characterizing prework 20 years ago. This effort is achieved in many ways, from the site visits to existing facilities performed by ProQuip to the 3D walkthroughs designed by McAbee Construction, Jacobs Applied Technology and Fluor Daniel.

For adequate use of prework, each case required extensive transportation planning and expediting. Careful analysis of shipping options and routes often dictated size and extent of prework. Howe-Baker maintained a specific department to solely handle expediting of equipment and other prework. Fluor Daniel extensively planned transportation routes, including options for expanding or improving infrastructure to meet the optimum prework size requirements.

Each of the companies stressed thorough shop testing and verification of prework components. For example, US Steel particularly took advantage of this to reduce outages to the steel furnaces and production lines. By testing equipment prior to installation, shutdown times could be minimized.

From a supply chain point of view, prework as a form of outsourcing lets the work be done where it is done best and cheapest, and it allows us to take advantage of economies of scale when projects can be assembled from off-the-shelf modular

components. Each company went to great lengths to monitor and maintain records of prework on and off the site.

In addition to these key characteristics of the prework, the data also revealed key enabling technologies that support the use of prework, shown in Table 4.3.

Table 4.3: Summary of Key Enabling Technologies

- | |
|--|
| <ul style="list-style-type: none">• Advanced computer design and visualization• Improved communication through IT• Advanced factory fabrication equipment• Advanced tracking technologies |
|--|

Each of the companies interviewed utilized some form of advanced computer design. The levels of use varied from well integrated 2D computer drawings to highly sophisticated 3D systems connected to component databases and producing walkthrough capabilities. The example of modularization in the pharmaceutical industry represents a case where 2D CAD was successfully used to track modular interfaces. Some cases, such as the examples for Jacobs Applied Technology, utilized 3D modeling to check interferences and connect to component information. Furthermore, McAbee Construction used 3D CAD to improve visualization and aid in educating parties with less experience with prework. The use of 3D CAD generally pays off in terms of communication, interference checking, re-use of design elements, and future application of automated design algorithms and intelligent web agents, but it requires some sophistication and corporate size.

All of the companies involved utilized information technologies to some degree to aid in the coordination efforts required of prework projects. The use of email and electronic file transfer was widespread. Some companies went further to develop intranets for in-house communication or limited client access. This can be clearly seen in the CTIW example. Other examples of IT use include digital imaging. Monitoring progress and identifying possible vendors through digital imaging was evident in the US Steel example of shopping for equipment in Australia via digital pictures and the internet.

Advances in computer-controlled equipment have also provided enablers for the prework industry. Prework facilitates the application of productivity enhancing automation such as robotics much easier than site work. Examples include CTIW's plasma steel cutting tables and McAbee Construction's automated vessel welders.

Prework may also benefit from advances in tracking technologies. By minimizing the total number of units used to construct a facility, prework should make materials management easier and make applications such as radio frequency tagging and bar coding more economical, since fewer expensive tags would be required. CTIW and US Steel have both implemented such technologies and connected them to material tracking databases.

In order to further show these comparisons between the companies with regards to these issues of technology and practices, Table 4.4 lists the characteristics of each including technology, decision tools and prework methods, as well as transportation capabilities. Most companies interviewed were involved in all three types of prework. Level of use with CAD varied. Some companies were involved in simply 2D CAD to check for interferences between systems and prework components. Companies classified as 3D CAD-Low used 3D CAD for design and coordination. Companies classified as 3D-CAD High used software not only for design and coordination but also for 3D walkthroughs or other types of animation beyond the design requirements. These technologies enabled increased visualization for prospective clients, as well as for project participants including operators and maintenance representatives. The next technology category includes digital imaging. Companies in this class used digital imaging and photos transferred electronically to communicate ideas and information. The final technology category is the internet. All the companies interviewed used the internet for electronic communication such as email and transferring files. This was clearly an industry standard, while 3D CAD and digital imaging has yet to gain complete acceptance.

Decision making techniques varied from company to company. While most agreed that a standard decision framework would be useful for determining prework feasibility both for internal and client justification, few companies had made efforts to develop tools or utilize tools already on the market. Companies classified as using the "in-house expert" method relied on the judgment of experienced project managers and data from previous projects. While this worked in most cases, these companies admitted that a third party tool

would be useful in justifying numbers to clients and also assisting less experienced staff with decision-making. Some firms developed tools in-house, such as Jacobs Applied Technology and Prosser. These tools combined the in-house expertise to develop a prework decision tool specific to their company. Only one of the companies interviewed, Fluor Daniel, revealed that that use an outside tool for analysis. Fluor Daniel uses MODEX to supplement in-house expertise.

Transportation capabilities, a key part in determining prework ability, were also tracked and listed in table. This included access by road, rail and barge and is described in detail within each company's trip report in Appendix B.

Table 4.4: Characteristics of Companies Interviewed

	Type of Prework			Information Technology					Decision Making			Transport		
	Prefabrication	Preassembly	Modularization	2D Checking	3D CAD-Low	3D CAD-High	Internet	Digital Imaging	In house expert	In house tool	Outside tool	Road	Rail	Barge
Central Texas Ironworks	X				X		X		X			X	X	
Eli Lilly Co.	X	X	X	X			X	X	X			X	X	X
McAbee Construction.	X	X	X			X	X	X	X			X	X	X
US Steel	X	X	X		X		X	X	X			X	X	
BE&K	X	X			X		X		X			X	X	X
Jacobs Applied Technology	X	X	X			X	X			X		X	X	X
ProQuip	X	X	X	X			X		X			X	X	X
Prosser	X	X	X			X	X			X		X	X	X
Fluor Daniel	X	X	X			X	X				X	X	X	X
Howe-Baker	X	X	X		X					X		X	X	X

Chapter 5: Decision Frameworks

OVERVIEW

The successful application of prework in construction requires good decision-making. The site visits and literature has shown that good decision-making begins with a clear understanding of the potential benefits and impediments to a project resulting from the use of prework. Depending on the nature of the project, participants and the prework, the analysis can vary. Analysis elements such as timing, information requirements, levels of involvement and communication requirements all factor into the decision process. Through the information gathered and research team feedback, decision frameworks were developed to aid project teams in determining the type and amount of prework best suited for a project.

In order to handle the varying requirements, several decision frameworks are proposed. These frameworks are presented as guidelines and represent the state-of-the-art in decision making at the time of the research. While large amounts of information went into development, the frameworks are mainly designed to promote thought among project participants rather than provide a complete solution. Projects by nature are generally unique and characteristics can vary greatly. While data for the framework development primarily came from industrial projects, the framework designers made efforts to allow flexibility and maintain relevance to many types of projects.

Since prework is considered more of as a spectrum of complexity than a all or nothing practice, the use of the decision frameworks suggested must allow for variable timing of decision making. Also, the degree to which a company requires justification of prework use will also determine the extent to which each framework is used for a particular type of prework. For example, one company may be comfortable basing its decision to use offsite preassembly on the results of a relatively subjective analysis of the project drivers and impediments at the strategic level. Another company may feel more comfortable with authorizing certain forms of prework only after thorough and detailed cost analysis. For these reasons, a decision timing map was developed by the research team to identify windows of opportunity. The map helps to guide the user through the timing of

the use of the proposed decision frameworks throughout the project life cycle and as they relate to different types of prework. This allows project decision makers to identify optimum windows of opportunity for framework usage and ultimately prework decisions. Types of prework were separated according to the requirements identified in the research.

The first and second decision frameworks are called “strategic” frameworks and are designed to provide relatively subjective insight into the applicability of prework based on project drivers and impediments. The term “strategic” was chosen because these frameworks look primarily at global project goals and objectives. The research showed that decisions regarding modularization and complex preassembly were typically based on market or project characteristics rather than detailed cost comparisons. Complex preassemblies can be defined as preassemblies requiring offsite fabrication and designs that differ from conventional stick built layouts without a difference in function or output. The strategic framework is broken down into two levels, one for initial screening and one for final decision analysis. Level I of the strategic framework is designed to provide early evaluation and screening of prework applicability during the business planning stages of a project. Level II digs deeper into the factors influencing modularization and complex preassembly, allowing project participants to make decisions regarding implementation at the optimum time in the project life cycle.

The third decision framework, called the “tactical” framework is focused on the more quantifiable analysis of the feasibility of prework and typically would be used for less complex prework such as simple preassemblies and prefabricated components. Simple preassemblies can be defined as preassemblies whose design does not vary significantly from their conventional, stick built counterparts. These preassemblies may be built on or offsite. The term “tactical” was more appropriate here because the framework focuses on greater detail and in some cases items that can provide local improvements but generally not global consequences. Since these decisions are typically made based on unit cost comparisons, the tactical framework has been set up as a numerical comparison.

DECISION FRAMEWORK TIMING MAP

The Decision Framework Timing Map was designed to identify recommended stages in the project lifecycle for using the proposed frameworks for determining prework

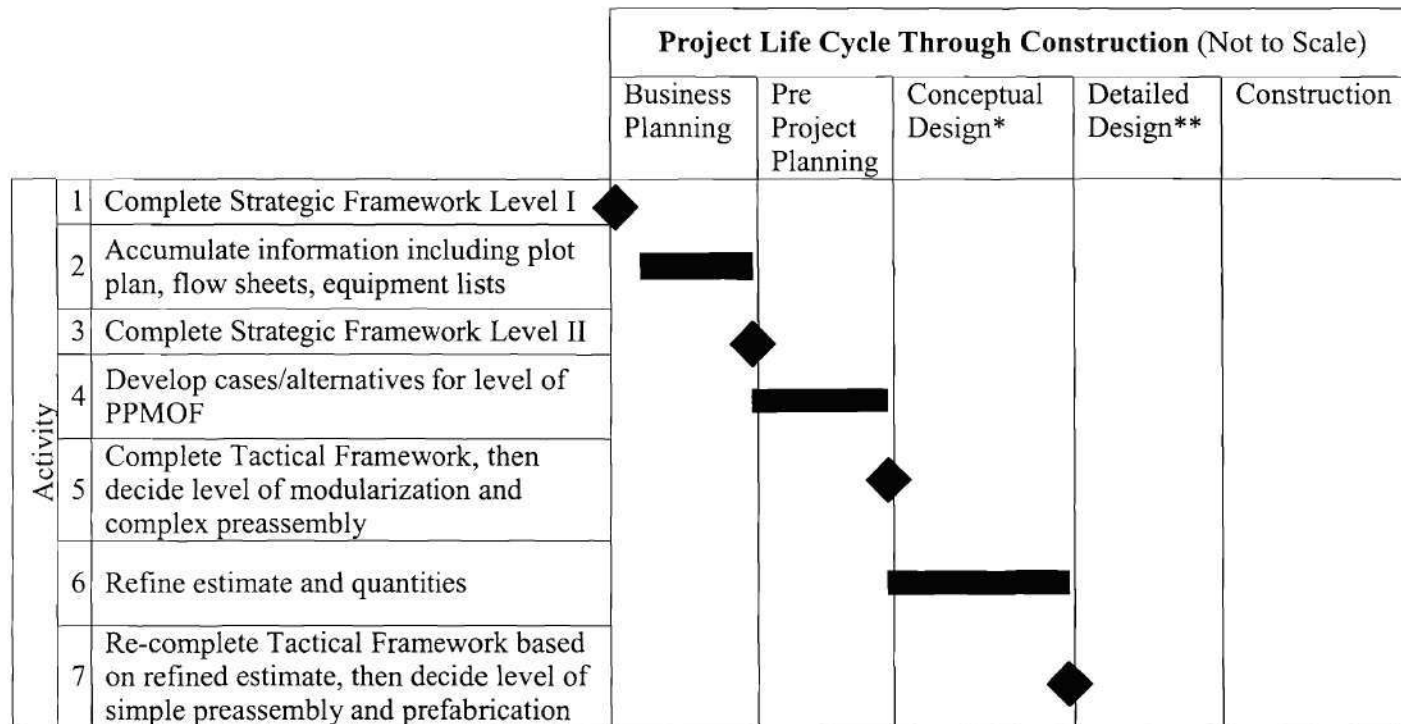
level and scope. The framework, shown in Figure 5.1, provides suggested timing for using the strategic and tactical frameworks for prework decisions. Decision timing considerations often depend on the level or type of prework. While earlier decisions were seen in the interviews as best for most situations, high degrees of prework were generally required to be decided early for optimum cost effectiveness. Modularization decisions were seldom made beyond the start of detailed design without large cost premiums associated with additional engineering and transportation logistics. Since modularization shipping envelopes and interfaces typically dictate many constraints of detailed design, early decisions are generally more successful. Additionally, the ordering of long lead items such as facility equipment, cranes and transporters must be carried out early enough to insure availability. In contrast, many decisions to preassemble or prefabricate components can still be made during or after the detailed design phase. In these cases, efficient use of prework is limited the level of design already complete.

Optimizing the benefits of complicated prework like modularization and complex preassemblies generally must begin at the layout of the plot plan and early enough to secure adequate shipping logistics. Attempting to optimize later in the design phase can result in reengineering and extensive design rework to achieve maximization of prework benefits. The cost of the additional effort may easily offset the benefits. However, the opportunity to maximize the benefits can still occur later for some preassembly and prefabrication. Provided the decision to carry out these forms of prework does not require the extensive design rework similar to the cases previously mentioned for modularization or complex preassembly, successful late decisions can be made. Even with this potential allowance of time, it is still proposed that decisions related to preassembly and prefabrication are best made in conceptual design. This allows the designer to detail drawings according to standard types of prework rather than trying to fit a prework component to a custom conventionally designed project.

To capture the above ideas, the timing map in Figure 5.1 lists a series of activities for using the frameworks and making decisions regarding prework. The process begins with the completion of the Strategic Framework Level I during the business-planning phase of the project. This framework provides a high level screening tool for project pre-planners to identify opportunities for prework to impact business objectives. Following the

completion of the Level I framework, the project team accumulates information regarding the project including plot plan, equipment lists and flow sheets that begin to define the project (Activity 2). Once this information has been gathered and the project has entered the pre-planning phase, the project team will complete the second framework, Strategic Framework Level II (Activity 3). Upon completion of the second framework, the team will have identified drivers and impediments for prework as related to the project under evaluation. Given these factors identified by the second framework, the team develops several different alternatives to the conventional or stick built project execution strategy (Activity 4). These alternatives, or cases, will involve varying levels of prework as identified by the Level II framework. At this point, the project has reached conceptual design and the project estimate will be approximately at $\pm 30\%$. With the cases and the estimates developed to this point, the project team will enter the case values and cost estimates into the third framework, the Tactical Framework (Activity 5). At the completion of this framework during conceptual design, it is suggested that the project team sets the level and scope of prework, at least for modularization and any complex preassemblies. The research has shown that this is generally the optimum time for these decisions. Delaying these decisions may result in decrease in project benefits. As previously mentioned, simple preassemblies and prefabrication may be delayed if design rework can be avoided. For this reason, the framework is recomputed when the estimate reaches $\pm 10\%$ and quantities have been determined before simple preassemblies and prefabrication is decided upon.

While focus of the timing of decisions regarding prework generally has been on the deadlines, many sources agreed that decisions could be made earlier. For example, some project teams begin in pre-planning with the goal to maximize prefabrication. Based on their previous experience with costs and vendors, the team did not have to carry out extensive evaluation such as presented in the Tactical Framework. In another similar situation, a company with very little prework experience had a champion of prework driving the decision who bypassed the detailed tactical process and made the decision earlier. Therefore, this timing map is a guideline for the decision process for prework. As companies become more experienced with the process, the frameworks and timing of decisions may be adjusted to fit the company.



* = At start of conceptual design: estimate approximately $\pm 30\%$, team has plot plan, equipment list, flow sheets

** = At start of detailed design: estimate approximately $\pm 10\%$, quantities determined

Figure 5.1: Timing of Decision Frameworks

STRATEGIC FRAMEWORK: LEVEL I

The purpose of Level I of the strategic decision framework, shown in Figure 2, is to provide insight into PPMOF potential very early in the project at the highest level of planning. It is designed to aid pre-project planners in identifying opportunities early in the business-planning phase based on major drivers and impediments to the use of PPMOF. This level contains a concise list of questions outlining these major drivers and impediments in order to determine initial feasibility of the use of PPMOF. These categories were developed based on the research and are located in the first column of the framework.

A question is presented for each of the categories along with a brief explanation of how PPMOF may influence the category. An answer of “yes” indicates that the factor in question could potentially be supported by PPMOF. For example, if the schedule factor was answered with a “yes”, there is potential for PPMOF to assist with alleviating schedule constraints.

After completing the five questions in the framework, the team will have identified potential areas for PPMOF use to be considered later in the project. By identifying these factors early, the framework provokes thought and discussion early in the project, preparing the team for the early decisions required for some types of PPMOF. Figure 5.2 shows the Strategic Framework Level I along with directions and instructions for interpretation.

Directions: Answer questions based on knowledge of project under consideration. Follow the interpretation and save the results for later use, as it will be combined with the results of the other two PPMOF tools for the final decisions regarding PPMOF.

Interpretation: Any sections answered “yes” or “maybe” are potential drivers for the use of PPMOF. Any sections answered “no” indicate no potential applicability of PPMOF to improve the factor. This guide is meant to be thought-provoking list to generate early discussion of PPMOF options to help reach project objectives. Further analysis and investigation through the Strategic Level II and Tactical Frameworks is necessary to calculate impact on project objectives in a more comprehensive manner.

Section	Question	No	Maybe	Yes
Schedule	Are their significant constraints or requirements for the project schedule? PPMOF may help to meet schedule constraints such as outage duration and time to market or decision needs.			
Labor	Is there a lack of good local labor available in the project area? PPMOF may help by moving work to areas with adequate labor.			
Safety	Is there an opportunity to decrease significant safety risks by using PPMOF? PPMOF may be able to relocate work to less hazardous environments such as ground level or controlled climates.			
Environmental, Legal and Regulatory	Are there significant environmental, legal and /or regulatory considerations that may constrain the project? PPMOF may help to alleviate constraints by relocating work while such issues are handled.			
Site Attributes	Are there significant site attributes such as extreme weather or lack of infrastructure that may impact project performance? PPMOF can potentially relocate work to more favorable conditions, subject to transportation requirements.			

Figure 5.2: Strategic Framework Level I

STRATEGIC FRAMEWORK: LEVEL II

The purpose of Level II of the strategic decision framework is designed to dig deeper into the areas highlighted in Level I to further determine prework feasibility as project definition increases. Level II broadens based on Level I categories and is designed for use during the pre-planning process as dictated by the timing map. Level II requires more knowledge about the project so it is carried out later in the pre-project planning and conceptual design phases. This knowledge may include site location, plot plan, processes, as well as general characteristics regarding infrastructure, required labor, permitting, and legal issues. The framework is separated into twelve sections, listed in Table 5.1.

Table 5.1: Strategic Framework Level II Categories

• Schedule	• Project and Contract Types
• Cost	• Quality
• Labor	• Design
• Safety	• Transportation
• Site Attributes	• Supplier Capability
• Mechanical Systems	• Lifting Requirements

Each section begins with a question followed by a series of factors related to the section and prework. Each factor is scored on a scale of -5 to 5, depending on how the factor answers the question posed. Figure 5.3 presents an example of the layout of the Level II framework. In the example, Section 1.0 handles the topic of schedule. The initial question states, "To what extent could pre-work have a positive, neutral, or negative impact on the following project issues or conditions related to schedule?" The first factor (1.1) is entitled "Quantifiable benefits due to shortened schedules." So in scoring this factor, the person or project team would ask itself, "To what extent could prework have an impact on shortening schedule?" The team then answers the question on the scale of -5 to 5. A score of 5 would mean that prework would have a positive impact on shortening schedule. To aid the team in determining the affect of prework, the column immediately right of the factor lists the way or ways prework could impact the factor. Furthermore,

examples identified in the research are also available in the back of the framework for each factor.

1.0 Schedule

1.1	Shortened schedules.	Pework may compress schedule through parallel activities and higher shop productivity rates.	-5	-2	0	2	5
-----	----------------------	--	----	----	---	---	---



(Supporting examples at end of framework)

1.1	Paper mill was constructed with prefabricated concrete beams, columns and walls to expedite construction process and time to dry-in for equipment installation.
-----	---

Figure 5.3: Schedule Example from Strategic Framework Level II

A score of 0 would indicate that the factor will not be impacted by prework. A score of -5 would indicate that the prework would have a greatly negative impact on the project with regards to the presented factor. Figure 5.4 demonstrates an example of where a -5 might be used in the transportation category. Given the question regarding transportation costs, a -5 might be marked if the project in question would have very high fees or costs associated with transporting prework to the site.

10.0 Transportation

10.2	Local transportation costs	Pework shipping may involve fees or other costs associated location or transportation route.	-5	-2	0	2	5
------	----------------------------	--	----	----	---	---	---



(Supporting examples at end of framework)

10.2	Dock fees may be assessed in some locations for barge shipments.
------	--

Figure 5.4: Transportation Example from Strategic Framework Level II

Upon completion of all of the questions in the Level II framework, the team would have begun to identify drivers and impediments to prework, as well as their relative weights. These drivers and impediments can then be used to develop cases or alternative designs to conventional stick built projects. These different cases will then be used as input for the next framework, the Tactical Framework.

The Level II framework was designed primarily from data from industrial projects. While many of the factors are common to many types of projects, it should be noted that the user of the framework might want to add questions to tailor towards other industries. Like the Level I and Tactical Framework, the Level II framework is designed to be a guide and a way of provoking thought rather than a comprehensive list of all of the factors influencing a project with regard to prework. The complete framework and supporting examples can be found in the following pages as Figure 5.5.

Strategic Framework: Level II

Directions: Answer the following questions based on how they relate to the project under evaluation. Each answer is scored on a scale from –5 to 5. An answer resulting in a –5 means that the factor or question is very strongly against prework. An answer of 0 is the result of a neutral consequence towards prework. A score of 5 represents a factor that strongly promotes or favors the use of prework. Further explanation of prework factors is provided at the end of this framework through examples of each factor.

Interpretation at Completion: This framework is meant to provoke thought among project planners by identifying critical ways prework could impact a project. Careful evaluation by the project team of factors scoring high or low will determine the applicability of prework on the project.

1.0 Schedule: To what extent could pre-work have a positive, neutral, or negative impact on the following project issues or conditions related to schedule?

1.1	Shortened schedules.	Pework may compress schedule through parallel activities and higher shop productivity rates.	-5	-4	-3	-2	-1	0	1	2	3	4	5
1.2	Planned shutdowns, outages, or turnarounds.	Maximizing assembly and verification prior to construction has the potential to reduce shutdown time.	-5	-4	-3	-2	-1	0	1	2	3	4	5
1.3	Late business decisions.	Pework has the potential to compress the installation schedule by utilizing higher shop productivity and multiple fabrication sites, allowing postponement of final business decisions.	-5	-4	-3	-2	-1	0	1	2	3	4	5
1.4	Early startup requirements.	Schedule compression resulting from multiple work sites and increased productivity at remote sites along with verification prior to installation can result in quicker and sooner startups.	-5	-4	-3	-2	-1	0	1	2	3	4	5
1.5	Timing of environmental or other project permitting.	Pework may allow work to begin offsite while site permits are being processed.	-5	-4	-3	-2	-1	0	1	2	3	4	5
1.6	Time limitations related to shipping and transportation.	Project locations may dictate the ability to ship, receive or install elements. Pework shipments may require timing with shipping or transportation windows.	-5	-4	-3	-2	-1	0	1	2	3	4	5

1.7	Equipment or materials with long lead-time.	Long lead items may dictate schedule regardless of level of prework. Such items may also control the level and scope of prework.	-5	-4	-3	-2	-1	0	1	2	3	4	5
1.8	Performing work activities out of the normal sequence.	Late activities can be preworked prior to start of installation to compress schedule or meet other project requirements.	-5	-4	-3	-2	-1	0	1	2	3	4	5
1.9	Risks associated with schedule penalties.	By reducing schedule risks associated with weather or labor conditions, prework may limit the risk of schedule penalties.	-5	-4	-3	-2	-1	0	1	2	3	4	5
1.10	Rewards for early project completion.	Schedule compression and/or reduction in schedule variance through prework may provide opportunities for incentives if available.	-5	-4	-3	-2	-1	0	1	2	3	4	5
1.11	Overall project schedule improvement	Prework may allow for improved overall schedules through compression and variance reduction.	-5	-4	-3	-2	-1	0	1	2	3	4	5
1.12	Requirements to get product to market rapidly	Prework may be able to reduce time to market through improved productivity rates in the shop and by desequencing activities. This may allow products to reach the market sooner.	-5	-4	-3	-2	-1	0	1	2	3	4	5

2.0 Cost: To what extent could pre-work have a positive, neutral, or negative impact on the following project issues or conditions related to cost?

2.1	Overall cost control.	Characteristics of prework may provide tighter cost control.	-5	-4	-3	-2	-1	0	1	2	3	4	5
2.2	Overall cash flow	Prework has the potential to provide more options for cash flow since work can be completed sooner or delayed without affecting targets.	-5	-4	-3	-2	-1	0	1	2	3	4	5
2.3	Requirements to meet new regulatory or other imposed requirements.	Compressing the schedule through the use of pre-work could allow the facility to attain compliance with the regulations by the mandated deadline.	-5	-4	-3	-2	-1	0	1	2	3	4	5

2.4	Requirements to get product to market rapidly	Pework may be able to reduce time to market through improved productivity rates in the shop and by desequencing activities. This may allow earlier return on investment.	-5	-4	-3	-2	-1	0	1	2	3	4	5
2.5	Future salvage value	Pework aspects of a project can be designed for salvage or reuse.	-5	-4	-3	-2	-1	0	1	2	3	4	5
2.6	Future modifications to or expansion of the facility.	Pework elements can be designed for duplication or expansion. Pework can also be designed for easy modification providing plant or manufacturing flexibility.	-5	-4	-3	-2	-1	0	1	2	3	4	5
2.7	Specific local economic factors	By relocating work offsite through prework, adverse local economic factors can potentially be avoided.	-5	-4	-3	-2	-1	0	1	2	3	4	5

3.0 Labor: To what extent could pre-work have a positive, neutral, or negative impact on the following project issues or conditions related to labor?

3.1	Labor Productivity	Pre-work labor productivity rates are potentially higher due to factors such as factory conditions. There are many cases where shop wage rates for pre-work are significantly lower due to multiple variables.	-5	-4	-3	-2	-1	0	1	2	3	4	5
3.2	Overall, peak or labor density requirements (quantity of workers)	Pework can relocate work to an area with a larger available workforce or workspace. Reducing onsite density of workers may provide productivity improvement opportunities.	-5	-4	-3	-2	-1	0	1	2	3	4	5
3.3	Local, regional, or national labor availability	Pework can relocate work away from adverse local, regional or national labor situations.	-5	-4	-3	-2	-1	0	1	2	3	4	5
3.4	Skill of labor that is available for the project	Pework can move critical work to locations where adequate skilled labor is available.	-5	-4	-3	-2	-1	0	1	2	3	4	5
3.5	Project-specific requirements such as licenses for craft workers	On projects with a lack of required licensed craft workers, prework may provide an economic alternative to bringing licensed workers to the site.	-5	-4	-3	-2	-1	0	1	2	3	4	5

3.6	Labor agreements or jurisdictional issues	Labor agreements or jurisdictional issues may limit the amount of work transferred offsite. Pre-work may be restricted or uneconomical based upon local tax incentives, pre-existing conditions requiring the use of local labor, craft labor agreements or others.	-5	-4	-3	-2	-1	0	1	2	3	4	5
3.7	Multiple projects in the same area that require substantial quantities of labor	Given a company with multiple projects drawing from one labor pool, prework may help to alleviate labor strains on other company projects.	-5	-4	-3	-2	-1	0	1	2	3	4	5
3.8	Remote locations with minimal infrastructure	Pework can reduce the need for establishing site infrastructure by reducing the size and duration of onsite labor.	-5	-4	-3	-2	-1	0	1	2	3	4	5
3.9	Anticipated escalation in labor cost	Work can be relocated through prework to areas with less labor volatility.	-5	-4	-3	-2	-1	0	1	2	3	4	5

53

4.0 Safety: To what extent could pre-work have a positive, neutral, or negative impact on the following project issues or conditions related to safety?

4.1	Unusual site or regional hazards	Offsite work can minimize necessary work in hazardous areas and reduce costs for protecting workers during traditional work methods.	-5	-4	-3	-2	-1	0	1	2	3	4	5
4.2	Ongoing facility operations	Reducing in the number of workers and types of crafts may reduce impacts on any ongoing operations.	-5	-4	-3	-2	-1	0	1	2	3	4	5
4.3	High labor density	Reducing in the number of workers and types of crafts may reduce exposure.	-5	-4	-3	-2	-1	0	1	2	3	4	5
4.4	Multiple shifts of construction workers	Onsite labor requiring multiple shifts may be relocated offsite through prework to reduce productivity decreases due to shift work.	-5	-4	-3	-2	-1	0	1	2	3	4	5

4.5	Increased risk from high elevations, confined spaces, known toxic atmospheres, etc.	Pework may reduce worker exposure in areas such as high elevations, wet or slippery environments, or trenches. The use of prework has the potential to bring a larger portion of work to a controlled environment at ground level.	-5	-4	-3	-2	-1	0	1	2	3	4	5
4.6	Contractual monetary incentives for a better project safety record	Reduced hazard exposure through prework may provide greater opportunity for monetary incentives associated with safety.	-5	-4	-3	-2	-1	0	1	2	3	4	5
4.7	Reductions in insurance costs	Reduction in exposure through prework may justify reduction in insurance costs.	-5	-4	-3	-2	-1	0	1	2	3	4	5
4.8	Heavy lifts	Pework may involve larger lifts, requiring further safety planning.	-5	-4	-3	-2	-1	0	1	2	3	4	5
4.9	Regulatory requirements	Safety regulatory requirements for onsite personnel may be reduced if work is relocated to areas with fewer requirements.	-5	-4	-3	-2	-1	0	1	2	3	4	5

54

5.0 Site Attributes: To what extent could pre-work have a positive, neutral, or negative impact on the following project issues or conditions related to site conditions and site access?

5.1	Anticipated weather conditions at the site	Pework can be done at remote locations where the weather is more predictable or controlled.	-5	-4	-3	-2	-1	0	1	2	3	4	5
5.2	Political issues	Pework can be relocated to areas with more favorable political climates.	-5	-4	-3	-2	-1	0	1	2	3	4	5
5.3	Environmental restrictions	Pework can move some work off plot or offsite where traditional methods would require additional considerations due to environmental restrictions.	-5	-4	-3	-2	-1	0	1	2	3	4	5
5.4	Local infrastructure to support the project	Pework can relocate activities to locations where there is adequate infrastructure such as supplies, vendors, housing or hotels, and power supply.	-5	-4	-3	-2	-1	0	1	2	3	4	5
5.5	Rights-of-way and property boundaries	The site must be checked for any areas that might restrict the transport of prework into the installation area.	-5	-4	-3	-2	-1	0	1	2	3	4	5

5.6	Laydown and staging space on the site	Pework such as preassembly requires additional space for assembly and preparation for installation.	-5	-4	-3	-2	-1	0	1	2	3	4	5
5.7	Access onto and on site	Space must be allotted for erection and installation equipment required for prework.	-5	-4	-3	-2	-1	0	1	2	3	4	5

6.0 Mechanical Systems: To what extent could pre-work have a positive, neutral, or negative impact on the following project issues or conditions related to mechanical systems?

6.1	Mechanical system density (amount of installed items in a given space)	Efficiencies in layout and quality control may be realized through prework of piping intense projects.	-5	-4	-3	-2	-1	0	1	2	3	4	5
6.2	Grouping or arrangement of mechanical systems	Grouping equipment into preassemblies or modules may provide advantages for construction efficiency or maintainability.	-5	-4	-3	-2	-1	0	1	2	3	4	5
6.3	Maintenance requirements for the facility	Pework design can take into account maintenance requirements provided information is made available at the time of design.	-5	-4	-3	-2	-1	0	1	2	3	4	5
6.4	Size of equipment of assembly	Equipment sizes of less than 14 feet provide opportunities to maximize advantages of prework while fitting most shipping envelopes. Projects with larger equipment may still benefit from partial prework.	-5	-4	-3	-2	-1	0	1	2	3	4	5
6.5	Special material assembly methods (alloy welding, etc)	Shop conditions provided by some forms of prework.	-5	-4	-3	-2	-1	0	1	2	3	4	5
6.6	Special assembly requirements such as "clean room" conditions	Some sensitive equipment can be preassembled and verified in a controlled environment, reducing risks of damage or exposure.	-5	-4	-3	-2	-1	0	1	2	3	4	5
6.7	Electrical system density	Pework designs can help consolidate high-density electrical systems.	-5	-4	-3	-2	-1	0	1	2	3	4	5
6.8	Electrical system routing requirements	Extensive routing requirements may require additional design for cross module wiring, increases design costs and fit up requirements.	-5	-4	-3	-2	-1	0	1	2	3	4	5

7.0 Project and Contract Types: To what extent could pre-work have a positive, neutral, or negative impact on the following project issues or conditions related to project type?

7.1	Replication on other projects	Pework is often conducted in repeatable structures that fit transportation envelopes. The result is a final product that may provide upgradeable or flexible designs.	-5	-4	-3	-2	-1	0	1	2	3	4	5
7.2	Proprietary technology or methods	Pework can be conducted at secure locations where proprietary items can be assembled and protected	-5	-4	-3	-2	-1	0	1	2	3	4	5
7.3	Project goals that include financial incentives	Schedule, cost and safety benefits resulting from prework could provide opportunities for maximizing incentives.	-5	-4	-3	-2	-1	0	1	2	3	4	5
7.4	Supplier/contractor flexibility to provide a facility that meets Owner's performance requirements	Allowing the prework supplier/contractor flexibility in design may lead to improved project performance.	-5	-4	-3	-2	-1	0	1	2	3	4	5

8.0 Quality: To what extent could pre-work have a positive, neutral, or negative impact on the following project issues or conditions related to quality?

8.1	Project specific quality requirements	Pework can be carried out in a controlled or predictable environment to reduce factors associated with low field quality.	-5	-4	-3	-2	-1	0	1	2	3	4	5
-----	---------------------------------------	---	----	----	----	----	----	---	---	---	---	---	---

9.0 Design: To what extent could pre-work have a positive, neutral, or negative impact on the following project issues or conditions related to design?

9.1	Availability of key project team members in early stages of the project development	Pework requires early involvement of many parties, including client, designer, and construction representatives.	-5	-4	-3	-2	-1	0	1	2	3	4	5
9.2	Early "freezing" of design	Many types of offsite prework require a certain level of design freeze prior to fabrication in order to meet transportation requirements.	-5	-4	-3	-2	-1	0	1	2	3	4	5
9.3	Project and/or Owner's organizational structure	Inexperienced or unformed project participants may require briefing on prework characteristics, benefits and requirements.	-5	-4	-3	-2	-1	0	1	2	3	4	5
9.4	3D CAD or similar design technology	Some complex designs for prework benefit from the ability to design with 3D CAD.	-5	-4	-3	-2	-1	0	1	2	3	4	5

9.5	Technology for information exchange among project participants	Increased coordination and information exchange required for prework can benefit from internet connections between participants.	-5	-4	-3	-2	-1	0	1	2	3	4	5
9.6	Compatibility of technology and computer systems	Communicating between multiple work sites such as fabrication shops may require upgrades in design and communication technology to insure compatibility.	-5	-4	-3	-2	-1	0	1	2	3	4	5

10.0 Transportation: To what extent could pre-work have a positive, neutral, or negative impact on the following project issues or conditions related to transportation?

10.1	Available transportation methods	Adequate truck, rail or barge transporters will be required depending on the size and weight of prework elements.	-5	-4	-3	-2	-1	0	1	2	3	4	5
10.2	Local transportation costs	Pework shipping may involve fees or other costs associated location or transportation route.	-5	-4	-3	-2	-1	0	1	2	3	4	5
10.3	Transportation infrastructure	Transportation routes must be evaluated to handle the proposed shipments.	-5	-4	-3	-2	-1	0	1	2	3	4	5
10.4	Permitting	Some areas require permits for loads of certain sizes and weights. Permits must be obtained to make transport feasible	-5	-4	-3	-2	-1	0	1	2	3	4	5
10.5	Risks of loss during transportation	Pework may include larger assemblies and increase the value of single shipments	-5	-4	-3	-2	-1	0	1	2	3	4	5
10.6	Impacts of weather conditions	Weather conditions may dictate prework shipping windows or transportation methods.	-5	-4	-3	-2	-1	0	1	2	3	4	5
10.7	Insurance and warranties during transport	Large prework shipments may carry significantly higher insurance coverage. Supplier warranties for prework must also be considered.	-5	-4	-3	-2	-1	0	1	2	3	4	5

11.0 Supplier Capability: To what extent could pre-work have a positive, neutral, or negative impact on the following project issues or conditions related to supplier capability:

11.1	Supplier availability	Supplier availability may affect lead times on deliverables.	-5	-4	-3	-2	-1	0	1	2	3	4	5
------	-----------------------	--	----	----	----	----	----	---	---	---	---	---	---

11.2	Supplier qualifications and capabilities for the specific project	Pework suppliers requirements may include certain certifications or levels of quality.	-5	-4	-3	-2	-1	0	1	2	3	4	5
11.3	Supplier shop capacity	Production, experience and quality characteristics of a supplier may dictate the scope of prework	-5	-4	-3	-2	-1	0	1	2	3	4	5
11.4	Supplier's information technology systems	Pework projects generally require increased coordination and communication between project participants. The use of electronic file transfer, email, 3D CAD and other electronic resources may be requirements for certain types of prework.	-5	-4	-3	-2	-1	0	1	2	3	4	5
11.5	Supplier support of project during all phases	Supplier representation may be required during installation, inspection or other aspects of the project.	-5	-4	-3	-2	-1	0	1	2	3	4	5

12.0 Lifting Requirements: To what extent could pre-work have a positive, neutral, or negative impact on the following project issues or conditions related to lifting requirements:

12.1	Availability of lifting and hauling equipment	While prework may reduce the duration of equipment on site. However, larger or heavier assemblies may require additional equipment support during installation. Site location and availability of equipment may affect scope of prework.	-5	-4	-3	-2	-1	0	1	2	3	4	5
12.2	Foundations required for prework items	Pework may require fewer or greater foundations than conventional methods, depending on the type and scope of the work.	-5	-4	-3	-2	-1	0	1	2	3	4	5
12.3	Heavy lifts and related planning	Large complex prework may require additional planning for heavy or oversized lifts.	-5	-4	-3	-2	-1	0	1	2	3	4	5

PREWORK SUPPORTING EXAMPLES FOR STRATEGIC FRAMEWORK LEVEL II

1.0 Schedule Examples:

1.1	Shortened schedules.	<ul style="list-style-type: none"> - Paper mill was constructed with prefabricated concrete beams, columns and walls to expedite construction process and time to dry-in for equipment installation. (BE&K)
1.2	Planned shutdowns, outages, or turnarounds.	<ul style="list-style-type: none"> - Steel producer installed new equipment to reduce shutdown of a critical furnace (US Steel) - Chemical producer built entire catalyst plant offsite first to reduce onsite congestion (BP, McAbee)
1.3	Late business decisions.	<ul style="list-style-type: none"> - Pharmaceutical company awaiting government approval of a product (Eli Lilly) - Product producer planning for market conditions/prices Wet acid plant built modular while permits were pending. (Rhone Poulenc, JAT) - Bulk chemical facility was estimated for both stick and modular construction. Since the modular schedule was a year shorter (2 years vs. 3 years stick), the owner opted to build modular but postpone construction one year. The postponement freed money for other projects for the year and allowed better design information to be obtained (Lilly).
1.4	Early startup requirements.	<ul style="list-style-type: none"> - Supplier facility goes online sooner, early to market with product
1.5	Timing of environmental or other project permitting.	
1.6	Time limitations related to shipping and transportation.	<ul style="list-style-type: none"> - Hurricane season in Angola, Caribbean - Ice flows in northern regions
1.7	Equipment or materials with long lead-time.	
1.8	Performing work activities out of the normal sequence.	<ul style="list-style-type: none"> - Security system installation on secure facilities is handled near project completion. Prework of these items reduces the time of installation and reduces exposure at the site. (State Dept) - Automation wiring and components for a pharmaceutical facility can be preassembled earlier in a project to compress schedule and reduce activities near the end of the project (Lilly). - Prefabricated rooms built out of sequence can be dropped in near end of project.

1.9	Risks associated with schedule penalties.	<ul style="list-style-type: none"> - Contract may dictate financial penalties for schedule overrun. - Prolonged exposure of worker's may increase safety risks. Workers installing security equipment in hostile country can reduce exposure to gunfire if items are preassembled (State Dept)
1.10	Rewards for early project completion.	
1.11	Overall project schedule improvement	
1.12	Requirements to get product to market rapidly	

2.0 Cost Examples:

2.1	Overall cost control.	<ul style="list-style-type: none"> - Prework in a shop could allow contingencies associated with weather conditions to be removed from the project estimate and reduce actual cost variance due to weather related effects as well.
2.2	Overall cash flow	
2.3	Requirements to meet new regulatory or other imposed requirements.	<ul style="list-style-type: none"> - Modular baghouses were installed in a steel production facility to meet regulatory requirements. Prework reduced crane usage. (US Steel)
2.4	Requirements to get product to market rapidly	
2.5	Future salvage value	
2.6	Future modifications to or expansion of the facility.	
2.7	Specific local economic factors	

3.0 Labor Examples:

3.1	Labor productivity	<ul style="list-style-type: none"> - Factory conditions associated with prework often provide increased efficiencies due to higher optimization of equipment usage and workplace layout. Shop overhead cranes, welding stations and fabrication jigs can be utilized for increased production capabilities. Controlled conditions such as indoor work, work at grade level and level workspaces can also provide potential for increased productivity. Comparisons should be based on all-in wage rates which include bare wages, equipment costs and productivity factors. - Polypropylene plant built modular to take advantage of labor productivity differences. (Arco Products, JAT) - Field productivity rates can be 25% lower than shop rates (1.2 vs. 0.9 gulf coast) with Field rate \$50/hr vs shop rate \$35/hr. (ProQuip) - Field (1.1) vs. shop (0.6) with Field \$45/hr vs. shop \$32/hr. (Howe-Baker)
3.2	Overall, peak or labor density requirements (quantity of workers)	<ul style="list-style-type: none"> - Pipe racks were built offsite to reduce onsite labor. (Conoco, JAT)
3.3	Local, regional, or national labor availability	<ul style="list-style-type: none"> - Chemical plant expansion was built modular to account for labor shortage. (Chevron, JAT) - Some local jurisdictions may require 2" and smaller pipe to be fabricated on site - Native American reservations, other countries or BLM may require the use of the local labor force for projects conducted in their areas - Tax advantages in some areas may be tied to the use of local labor on the project.
3.4	Skill of labor that is available for the project	
3.5	Project-specific requirements such as licenses for craft workers	
3.6	Labor agreements or jurisdictional issues	<ul style="list-style-type: none"> - Some local labor laws governing projects may require pipe below 2" diameter to be fabricated onsite.
3.7	Multiple projects in the same area that require substantial quantities of labor	
3.8	Remote locations with minimal infrastructure	
3.9	Anticipated escalation in labor cost	

4.0 Safety Examples:

4.1	Unusual site or regional hazards	<ul style="list-style-type: none"> - Pework may have less requirements for special skills in the shop environment. For example, a skilled worker may oversee more unskilled personnel in the shop. - Prefabricated, preassembled ventilation systems installed in a steel furnace reduced worker exposure to hazardous operations. (US Steel) - Pesticide plant was built modular due to OSHA site restrictions. (Rhone Poulenc, JAT) - A site with repetitive disruptions due to gas alarms reduced productivity (Kvaerner Process)
4.2	Ongoing facility operations	<ul style="list-style-type: none"> - Equipment in a steel mill was preassembled to reduce construction impact on existing operations. (US Steel) - Chemical plant expansion built modular to reduce impact on existing operations. (Chevron, JAT)
4.3	High labor density	<ul style="list-style-type: none"> - In some cases, peak onsite labor can be reduced 40%. (ProQuip)
4.4	Multiple shifts of construction workers	
4.5	Increased risk from high elevations, confined spaces, known toxic atmospheres, etc.	<ul style="list-style-type: none"> - Chemical process facilities were built using prework at ground level to reduce high work. (JAT, ProQuip, Howe-Baker, McAbee, BE&K, Dupont)
4.6	Contractual monetary incentives for a better project safety record	
4.7	Reductions in insurance costs	
4.8	Heavy lifts	
4.9	Regulatory requirements	

5.0 Site Attribute Examples:

5.1	Anticipated weather conditions at the site	<ul style="list-style-type: none"> - Cold, monsoons, desert
5.2	Political issues	<ul style="list-style-type: none"> - Projects located in Central or South American regions undergoing civil unrest or terrorist activities may benefit from relocation of work to offsite fabrication facilities. - Political regions may include requirements for percentage of fieldwork.

5.3	Environmental restrictions	<ul style="list-style-type: none"> - Elevated highways over wetlands - In some cases, local burdens in terms of noise, dust, water use, wetland impacts, air/water quality may dictate prework.
5.4	Local infrastructure to support the project	<ul style="list-style-type: none"> - Existing pipe racks, road limitations, overhead clearance, culverts, bridges, utilities and other site obstacles may require removal and/or replacement.
5.5	Rights-of-way and property boundaries	
5.6	Laydown and staging space on the site	
5.7	Access onto and on site	

6.0 Mechanical System Examples:

6.1	Mechanical system density (amount of installed items in a given space)	<ul style="list-style-type: none"> - Process areas in chemical plants - In some cases, density may be defined as less than 75-100 sf per worker (Kvaerner Process)
6.2	Grouping or arrangement of mechanical systems	<ul style="list-style-type: none"> - Grouping equipment reduces piping and wiring material required, as well as may reduce maintenance. (Prosser)
6.3	Maintenance requirements for the facility	
6.4	Size of equipment of assembly	<ul style="list-style-type: none"> - Large reactors may not fit shipping envelope, but surrounding elements may be constructed using prework (JAT).
6.5	Special material assembly methods (alloy welding, etc.)	<ul style="list-style-type: none"> - Glass lined pipe for acid - Titanium - Double containment may be required for chrome welding
6.6	Special assembly requirements such as "clean room" conditions	<ul style="list-style-type: none"> - Gas chromatograph - Pharmaceutical or biotechnology equipment
6.7	Electrical system density	
6.8	Electrical system routing requirements	

7.0 Project and Contract Type Examples:

7.1	Replication on other projects	<ul style="list-style-type: none"> - Modular construction provided opportunities for future expansion for a pharmaceutical facility. (Eli Lilly) - Reusability, interchangeability and reconfiguration capabilities may result from prework.
7.2	Proprietary technology or methods	<ul style="list-style-type: none"> - Process technology developer protects proprietary components with prework. (Howe-Baker)
7.3	Project goals that include financial incentives	<ul style="list-style-type: none"> - Performance incentives on a chemical process project allowed shared savings of \$1.7MM and a safety bonus of \$40M, both attributed in part to prework.
7.4	Supplier/contractor flexibility to provide a facility that meets Owner's performance requirements	<ul style="list-style-type: none"> - Prework providers prefer to control destiny through turnkey, lumpsum contracts. (ProQuip, Howe-Baker) - Controlling both engineering and construction allows full benefits from productivity gains. - Some suppliers may have reusable designs that could fulfill owner requirements. - Reference plants (Bechtel) - Cookie cutter cogeneration facilities

8.0 Quality Examples:

8.1	Project specific quality requirements	<ul style="list-style-type: none"> - Orbital welding - 100% welding NDE, testing, x-ray capabilities in shop - Positive material identification for alloy testing in shop - Verification of P&IDs, receipt verification and faster inspections in shop (Lilly) - Bolt verification in embassy doors (State Dept)
-----	---------------------------------------	---

9.0 Design Examples:

9.1	Availability of key project team members in early stages of the project development	
9.2	Early "freezing" of design	<ul style="list-style-type: none"> - Items such as equipment size, number, and location are most efficiently frozen early. Changes late in the prework construction process negate initial predicted benefits.

9.3	Project and/or Owner's organizational structure	<ul style="list-style-type: none"> - Many cultural impediments exist regarding prework. Many project participants see prework, especially modularization, as a cramped skid with little accessibility for maintenance or operation. Prework providers or owners working to convince upper management to implement prework often need to present successful recent cases to demonstrate prework effectiveness. Overcoming cultural difficulties may require a champion who drives the concept with the authority required. - Compiling lessons learned from previous prework experiences and incorporation in construction practices has helped to reduce cultural biases within one large owner company. (Lilly)
9.4	3D CAD or similar design technology	<ul style="list-style-type: none"> - 3D CAD allows walkthroughs, improved visualization, and interference checking. Communication of ideas and layout are also quicker through 3D images.
9.5	Technology for information exchange among project participants	<ul style="list-style-type: none"> - The internet allows faster transmission of design information and allows faster and quicker updates.
9.6	Compatibility of technology and computer systems	

10.0 Transportation Examples:

10.1	Available transportation methods	
10.2	Local transportation costs	<ul style="list-style-type: none"> - Dock fees may be assessed in some locations for barge shipments.
10.3	Transportation infrastructure	<ul style="list-style-type: none"> - Bridge load restrictions, turning curve radii, road width and overpass clearance may restrict size and weight of prework components. Other restrictions may include overhead power lines, grade limitations, seasonal road load limits, and rail restrictions for size and weight.
10.4	Permitting	
10.5	Risks of loss during transportation	<ul style="list-style-type: none"> - Large prework items such as complete modular plants may be shipped on a single barge and therefore increase risk. - Hostile locations may present increased risks
10.6	Impacts of weather conditions	<ul style="list-style-type: none"> - Routes through inclement areas such as hurricane or typhoon regions, frozen waters or other weather conditions may dictate shipping windows.
10.7	Insurance and warranties during transport	<ul style="list-style-type: none"> - Some prework vendors provide warranties based on shipping date and/or startup. One typical contract may last 18 months after shipment or 12 months after start up.

11.0 Supplier Capability Examples:

11.1	Supplier availability	
11.2	Supplier qualifications and capabilities for the specific project	<ul style="list-style-type: none"> - A supplier requirement for structural steel preassemblies for a chemical plant included tons per month of prefabricated elements. (Dupont, BE&K) - Supplier may be required to handle a certain amount of testing capacity, such as hydrotesting or x-ray testing. - Welding certifications may be required for certain types of prework.
11.3	Supplier shop capacity	
11.4	Supplier's information technology systems	
11.5	Supplier support of project during all phases	

12.0 Lifting Requirements Examples:

12.1	Availability of lifting and hauling equipment	<ul style="list-style-type: none"> - Work in Alaska required lifting equipment to be shipped up from the lower 48 states to accommodate prework requirements for lifting.
12.2	Foundations required for prework items	
12.3	Heavy lifts and related planning	

Figure 5.5: Strategic Framework Level II

TACTICAL FRAMEWORK

The goal of the tactical decision framework is to provide a quantifiable cost analysis of the impact of PPMOF strategies on a project. It is designed to provide quantitative cost data for the project team based on the impact of PPMOF on cost, labor and schedule. The suggested timing of the analysis would take place during the conceptual design and in some cases again later in the beginning of detailed design, as shown in the Decision Framework Timing Map. Some projects or management structures may call for more than one cost analysis based on varying levels of funding requirements or information availability. For example, a project team may request a tactical analysis at $\pm 30\%$ estimate and again at $\pm 10\%$ for decisions regarding prefabrication.

Where the strategic frameworks focused on global project goals and objectives, the tactical framework focuses more on a more detailed level of project analysis. While a high level of detail may not be required for decisions regarding modularization and complex preassembly, the research showed that many types of simple preassembly and prefabrication decisions were often based on detailed cost, labor and schedule comparisons with conventional options. Regardless of the level or type of PPMOF, most cases call for some form of cost comparisons. To achieve this, the Tactical Framework layout consists of a series of steps, shown in Figure 5, for determining cost impact based on cost additions and benefits, as well as labor and schedule impacts of PPMOF.

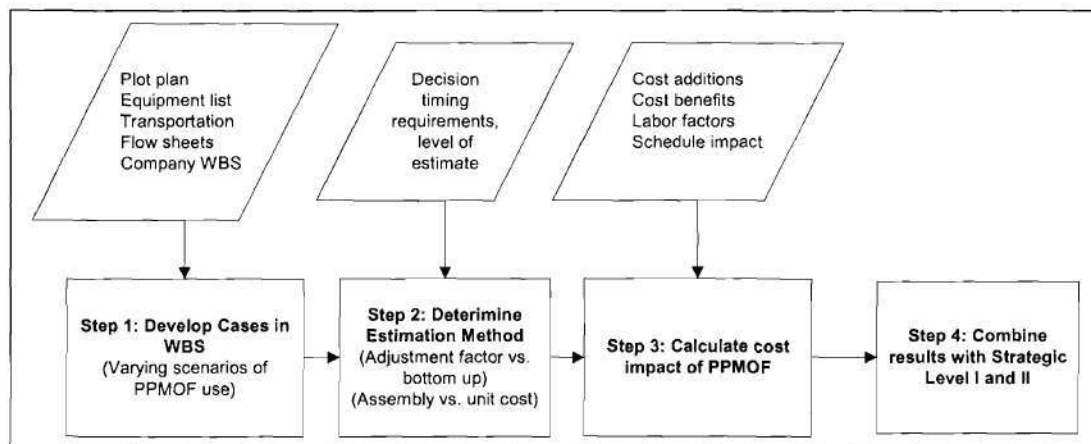


Figure 5.6: Breakdown of Tactical Framework Process

The tactical framework is presented with the idea that these suggestions be implemented with a company's existing decision and estimating process. This research team chose not to develop a new estimating tool, as it would be difficult to create a single system that fits most company systems.

Prior to completing the Tactical Framework, the project team will have completed the Strategic Framework Level II and obtained project information (including plot plan, equipment list, transportation constraints and flow sheets). This information will be used to complete Step #1, the development of cases using varying levels of PPMOF and the company work breakdown structure (WBS). These cases are to be developed based on the drivers and impediments specific to the project in question as identified by the Strategic Framework Level II.

These case examples may include a conventional, stick built option; a project with maximized modularization; or a project with some preassemblies and prefabrication. Table 5.2 represents an example of one case for a hypothetical project. For this case, approximately 30% of the project will involve PPMOF. In the first column, each type of PPMOF is listed. Beside each type of PPMOF is the part of the project that is proposed to contain PPMOF. In the example, a reactor in area 1 of the plot plan will be constructed as a module.

Table 5.2: Example of Case Option

Case #1: 30% PPMOF	
Modules	<i>e.g. Reactor in Area 1</i>
Preassemblies	<i>e.g. Compressors in Area 2,3</i>
Prefabrication	<i>e.g. Pipe Spools in Area 3,4,5</i>

Once the cases have been identified and proposed levels and scopes of PPMOF have been determined, the Tactical Framework will aid in determining cost, schedule and labor impact. Further development of these cases begins with the WBS. The level of detail required for the decision for finalizing the project execution plan will determine the level

of detail of the WBS and methods for analysis. Upon completion of case development, the cases should be next structured according to the company WBS.

Based on the level of PPMOF and WBS breakdown, these more detailed cases can be used for the analyses of cost, schedule, and labor impact. Prior to determining the cost impact, a method of estimation must be selected, as outlined in Step #2. Methods of determining cost impact may vary depending on the level of detail required. The estimator may choose to utilize cost adjustment factors or bottom up estimation strategies. Sections of the project may be looked at from a unit cost or an assembly standpoint. For example, an estimator may estimate that PPMOF will add 10% more structural steel to an assembly on the project. This cost adjustment factor applied to an assembly will provide a high level estimate for the cost impact of PPMOF. For a more detailed analysis, a bottom up strategy could be applied to items at the unit cost level. For example, productivity rates could be used to estimate the labor component of piece of work. Steel erection work relocated from 100 feet in the air to ground level in a shop may be estimated as more efficient. Therefore, the unit cost of steel would be adjusted based on altering the labor component of the cost.

Upon selection of the estimation method, the tactical framework moves into Step #3 of the process, the actual calculation of PPMOF cost impact, summarized in Figure 5.7.

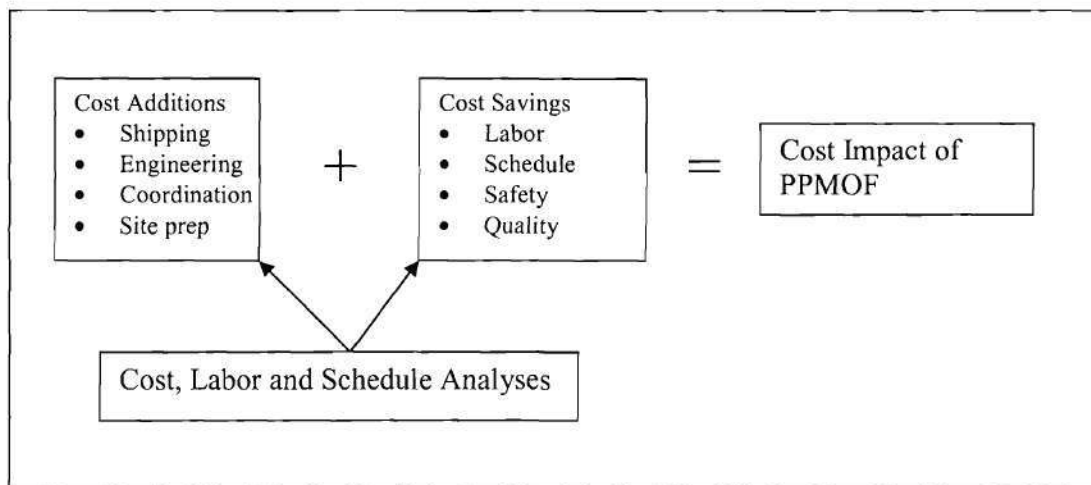


Figure 5.7: Breakdown of Tactical Framework Step #3

The cost impact is based on the combination of additional costs and cost savings resulting from the use of PPMOF. The determination of these additions and savings is based on the cost, labor and schedule analyses, described in the following sections.

Cost Analysis

Sources of cost data include historical company data, estimates obtained from contractors and/or in-house estimates based on the WBS.

Once a decision is made with regards to how the estimation will proceed, the next task is to determine the areas of impact PPMOF will have on the estimate. Tables 5.3 and 5.4 provide lists of cost and savings factors identified through the research that could potentially be included in a cost estimate for PPMOF.

Table 5.3: Additional Costs Generally Associated with PPMOF

Shipping	<ul style="list-style-type: none"> - Access route prep - Transporter cost
Site preparation	<ul style="list-style-type: none"> - Access - Road construction - Obstruction removal - Laydown area acquisition - Laydown area prep
Equipment	<ul style="list-style-type: none"> - Lifting equipment - Lift plan development - Additional lifting rigs
Site impacts	<ul style="list-style-type: none"> - Reduction in ongoing operations
Increased coordination	<ul style="list-style-type: none"> - Additional client planning meetings - Additional internal planning meetings - Cost to transfer information from design office to shop
Increased Engineering	<ul style="list-style-type: none"> - Additional structural supports - Additional rigging design

Table 5.4: Cost Savings Generally Associated with PPMOF

Labor Savings	<ul style="list-style-type: none"> - "All in" wage rate differences - Amount of hours transferred offsite
Schedule Savings	<ul style="list-style-type: none"> - Labor productivity differences
Safety	<ul style="list-style-type: none"> - Safety bonuses from project - Insurance savings due to reduced exposure - Insurance savings due to reduced rates
Quality	<ul style="list-style-type: none"> - Rework reduction

Labor Analysis

In addition to cost concerns associated with PPMOF, labor costs and the associated risk analysis is the second major factor for consideration in the tactical framework. Labor affects both cost and schedule through differences in wages and productivity. Factory conditions associated with PPMOF often provide increased efficiencies due to higher optimization of equipment usage and workplace layout. Shop overhead cranes, welding stations and fabrication jigs can be utilized for increased production capabilities. Controlled conditions such as indoor work, work at grade level and level workspaces can also provide potential for increased productivity. Comparisons should be based on all-in wage rates that include bare wages, equipment costs and productivity factors.

The site visits conducted by the research yielded many examples of labor differences between conventional and PPMOF. In some cases, all-in wage rate (base wage, fringe and equipment) differences were estimated at 30% lower for work conducted in the shop. In addition, it was not uncommon for PPMOF providers to claim a 25% or more increase in productivity over field labor. Table 5.5 lists reasons for productivity improvement.

Table 5.5: Reasons for Productivity Improvement through PPMOF

<ul style="list-style-type: none">• Ground level work• Easier access to tools• Increased opportunity for automation• Easier access to information	<ul style="list-style-type: none">• Controlled weather and lighting• Reduced supervision requirements• Lower work density• Overall improved motivation of the worker
--	---

Once wage rate and productivity data has been collected, cost savings associated with the use of PPMOF can be estimated to assist with the decision process. In Table 5.6, two cases are compared. Case 1 is based on 100 % stick built while Case 2 divides the amount of stick versus PPMOF by 70/30, respectively. The result shows that in this case, PPMOF can potentially reduce labor cost by \$6 million, or 12%, based on just the wage rate and productivity differences. By also including risk reduction, savings could potentially increase.

Table 5.6: Calculating Labor Cost for PPMOF Projects

	Type of Work	Productivity Factor	Man Hours	Cost per Hour (all-in)	Total Labor Cost
Case 1	100% Stick Built	1.00	1,000,000	\$50	\$ 50 Million
Case 2	70% Stick Built	1.00	700,000	\$50	\$ 44 Million
	30 % PPMOF	1.25	240,000	\$35	

Managing labor risk is another important aspect when considering PPMOF for a project. Risks associated with delays, safety, along with labor availability, retention and attraction can all potentially be more easily mitigated by PPMOF. With regards to weather delays, PPMOF has the potential to lower risks of weather delay due to inside work. Relocating work off-site can also potentially alleviate delays associated by permitting. Also, safety risks can potentially be reduced through the increased capacity to perform work at ground level and the controlled atmosphere of the shop. Fabrication shops often do not have the same variations in temperature, water, mud and other less predictable factors associated with the construction site. In addition, risks associated with labor availability, attraction and retention can also be lessened by PPMOF. Projects in areas with insufficient labor can potentially benefit from the relocation of work to shops with adequate work forces. Labor attraction and retention may also be improved by relocating work to the shop. Workers are increasingly placing greater emphasis on family time and work conditions over pay. In the past, many workers enjoyed the nomadic lifestyle of traveling to remote sites. More workers now are requesting more permanent work locations, more favorable work conditions, and predictable hours.

Table 5.7: Labor Risks and PPMOF Factors that Help Mitigate

Weather Delays	PPMOF work can often be completed indoors
Permit Delays	PPMOF work can often be completed offsite while permits are being acquired.
Worker Safety	Work can more easily be performed in controlled shop environment at ground level
Labor Availability	Work can be relocated through PPMOF to areas with more adequate labor.
Labor Retention and Attraction	Workers often prefer jobs with more consistent locations, hours and work environment.

Schedule Analysis

In addition to calculating cost and labor impacts due to PPMOF, the third area of the tactical tool involves schedule impact. Especially for complex PPMOF such as modularization, schedule is the main driver and therefore the estimate of schedule reduction becomes a major component of the decision process. While labor timing, density and work hour curves will vary from project to project, approximate schedule reduction estimates can be made based on labor productivity differences and schedule compression due to relocating work. Numbers for productivity rates can be obtained from historical records or through verified contractor estimates. Schedule compression will in part be determined by the amount of work transferred off site creating parallel activities. Work relocated off site during permit acquisition may also be a factor. Figure 5.8 provides an example of the difference in schedule between an all stick built project and a project with some work transferred off-site. In this example, one month has been eliminated on the front end and two on the end with PPMOF. The example was based on relocating 40% of the hours offsite with PPMOF and with performance factors for stick built and shop of 1.0 and 1.3, respectively.

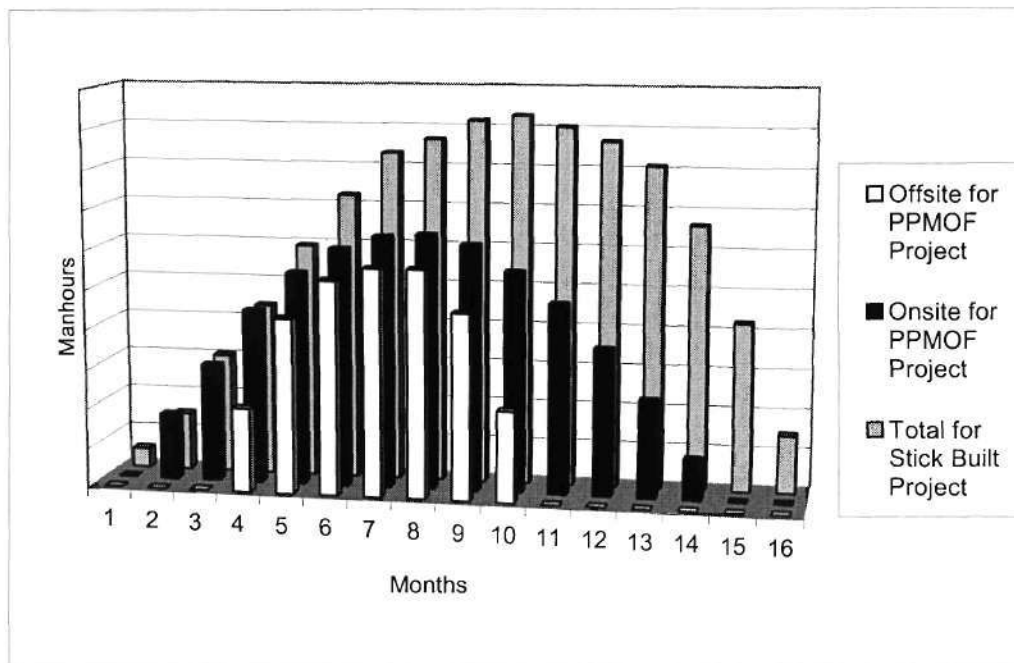


Figure 5.8: Schedule and Labor Hour Comparison

Reaching project team consensus on the quantification of cost benefits of the schedule reduction and relocation has proven to be a challenge. Unless the owner, contractor and engineering are willing to share cost and financing data, adequate quantification of schedule cost benefits is difficult if not impossible. For maximization of the cost benefit of PPMOF, some level of agreement on schedule impact must be reached.

Interpretation of Tactical Framework

Step #4 is the combination of the tactical portion of the decision process with the project objectives determined in the Strategic Frameworks Level I and II. By combining the results of the three tools, the team can then work to reach the final decision for how PPMOF will impact the project execution plan.

INTERPRETATION OF FRAMEWORK RESULTS

Once the three frameworks have been completed, the project team can review the results of the work to reach a decision regarding PPMOF implementation. This analysis

allows the team to review the “big picture” drivers from the Strategic Level I framework with the project objectives from Level II and the cost impact from the Tactical Framework. These three tools will then together aid in the decision to use PPMOF and the development of a project execution plan.

TRIANGULATION AND VERIFICATION OF DATA

The entire process of data collection, structuring and revision of the frameworks presented included triangulation and verification by the team. Data collected through the literature review and site visits was presented to the experts on the research team for verification. For example, a benefit of prework such as outage reduction could be triangulated and verified through the literature, site interviews and experience of research team members. Furthermore, data collected in interviews was verified through interviewing both multiple people within a company separately and through interviewing owners, designers, contractors and suppliers from the same projects.

While this verification assisted in validating the data and general structure of the frameworks presented, further work would be required to validate the overall scoring and usage of the frameworks. It is therefore recommended this verification could be handled through dissemination of the framework into the industry for beta testing and side-by-side use with existing methods to evaluate value added. After verifying the scoring and usage, the frameworks could be used as a metric for comparison with project performance.

Chapter 6: Conclusions and Recommendations

CONCLUSIONS

- Prefabrication and simple preassembly decisions are typically based on unit cost considerations at the tactical level.
- Modularization and complex preassembly decisions are typically based on broad project factors at the strategic planning level.
- The main impediment to the use of prework is the lack of related expertise that exist in the industry. Advances in 3D presentation and the growth of successful facilities using prework are ways the industry is addressing this concern.
- Information technologies are helping to overcome the extra requirements of design, coordination, communication and organization associated with prework. 3D CAD and other modeling software are allowing more efficient design of all types of prework. Information technologies such as electronic file transfer, email and digital imaging are helping to overcome the coordination, communication and organizational challenges.
- Prework by nature has the potential to address many of the recurring construction industry challenges including workforce issues, tighter budgets and increased needs for schedule compression.

RECOMMENDATIONS

- The frameworks designed and proposed through the research effort should be beta tested with companies currently using prework. This will help to validate and revise the frameworks as necessary.
- Scores from the frameworks should be used to build metrics for prework. These metrics can then in turn be used to compare against traditional project performance metrics. For example, the score from the Strategic Level II framework could be combined with a metric describing the level of prework of the finished project so both could be compared to the project performance with regards to cost, schedule, quality and others. One would predict that a project with a level of prework that corresponds to the level proposed by the frameworks would also be associated with superior project

performance. For example, if the frameworks suggested maximization of prework to achieve schedule goals and the project execution plan matched this plan, one would expect the project to perform well in meeting the schedule goals.

- The frameworks presented should be expanded and revised to fit different industries. While the information for this framework primarily was from the industrial sector, the frameworks could be further tailored for industries such as commercial, heavy civil or residential.

Appendix A: Site Visit Interview Guides

OWNER VERSION

1. Profile

- 1.1. Company/Project name
- 1.2. Type of industry
- 1.3. Type of work
- 1.4. Location
- 1.5. Contact information/People interviewed
- 1.6. How is PPMOF used the company/on the project?
- 1.7. What percentage of work is PPMOF?

2. General Questions regarding PPMOF

- 2.1. What are the drivers? (Schedule, Technology, Economic, Workforce etc.)
- 2.2. What are the project objectives and how do they influence the use of PPMOF?
- 2.3. What are the benefits? (Quality, Environmental Impact, Onsite congestion, Site conditions, Manufacturing conditions, Craft productivity, Labor rate, Overall cost, Schedule duration/ Decrease time to market, Ground level work, Onsite construction, etc.)
- 2.4. What are the impediments? (Amount of preplanning, Inflexibility, Transportation, Change in project risk, Amount of project coordination, Procurement, etc.)

3. Recent Developments

- 3.1. Technology - Compared to 15 years ago, how have the following affected the use of PPMOF?
 - 3.1.1. Equipment
 - 3.1.2. Design (3D CAD, 4D CAD, etc.)
 - 3.1.3. Information technology (Internet, intranet, EDI, bar coding, etc.)
- 3.2. Economics
 - 3.2.1. How has the economy and labor situation played a role in the decision to use PPMOF?

4. Future of PPMOF

- 4.1.1. What areas of new applications of PPMOF have the highest potential?
- 4.1.2. What are the barriers to the implementation of these new applications?

5. Decision Making

- 5.1. How is the owner involved in the decision process?
- 5.2. What factors considered in analyzing possible use of PPMOF?
- 5.3. What are the key criteria used to make the decision?
- 5.4. How is preplanning involved in the decision making process?

- 5.5. Who makes the decision to use PPMOF?
- 5.6. How is the decision made?
 - 5.6.1. At what stages in a project are decisions made most successfully?
 - 5.6.2. How does PPMOF affect preplanning?
 - 5.6.3. Are there flexibility issues?
 - 5.6.4. How do you determine the level of PPMOF?
 - 5.6.5. Does your company have a specific decision making process for the use of PPMOF?
 - 5.6.6. What are the best practices in assessment and decision-making regarding possible use of PPMOF?
 - 5.6.7. Other key considerations or aspects of the decision making process?

6. Information requirements and flow using PPMOF

- 6.1. How have new technologies affected the flow of information between the key players? (Such as internet, intranet, EDI)
- 6.2. What level of information exchange is required for a PPMOF project? At which phases?
- 6.3. What experience and knowledge is typically required by the owner of the contractor/engineer?
- 6.4. Are there security issues?
- 6.5. Are there standards for information exchange?
- 6.6. Coordination needs
 - 6.6.1. How is coordination handled in general between the owner, contractor, designer, fabricator, and/or supplier?
- 6.7. Other considerations for information requirements

7. Contracts/Project Delivery

- 7.1. What types of contracts are typically used?
- 7.2. How is payment made?
- 7.3. What project delivery method is typically used? (Turnkey, DB/EPC, EPCM, DBOO, DBB, Maintenance)

ENGINEERING/CONTRACTOR VERSION

1. Profile

- 1.1. Company/Project name
- 1.2. Type of industry
- 1.3. Type of work
- 1.4. Location
- 1.5. Contact information/People interviewed
- 1.6. How is PPMOF used the company/on the project?
- 1.7. What percentage of work is PPMOF?

2. General Questions regarding PPMOF

- 2.1. What are the drivers? (Schedule, Technology, Economic, Workforce)
- 2.2. What are the project objectives and how do they influence the use of PPMOF?
- 2.3. What are the benefits? (Quality, Environmental Impact, Onsite congestion, Site conditions, Manufacturing conditions, Craft productivity, Labor rate, Overall cost, Schedule duration/ Decrease time to market, Ground level work, Onsite construction)
- 2.4. What are the impediments? (Amount of preplanning, Inflexibility, Transportation, Change in project risk, Amount of project coordination, Procurement)

3. Recent Developments

- 3.1. Technology - Compared to 15 years ago, how have the following affected the use of PPMOF?
 - 3.1.1. Equipment
 - 3.1.2. Design (3D CAD, 4D CAD, etc.)
 - 3.1.2.1. Visualization
 - 3.1.2.2. Interference checking/field fitting reduction
 - 3.1.3. Information technology (Internet, intranet, EDI, bar coding, etc.)
 - 3.1.3.1. Coordination
 - 3.1.3.1.1. Lead times
 - 3.1.3.1.2. Access to drawings/information
 - 3.1.3.1.3. Other
 - 3.1.3.2. Organization
 - 3.1.3.2.1. Participant communication
 - 3.1.3.2.2. Levels of involvement
 - 3.1.3.2.3. Integration of multiple sites
 - 3.1.3.2.4. Other
- 3.2. Economics
 - 3.2.1. How has the economy and labor situation played a role in the decision to use PPMOF?

4. Future of PPMOF

- 4.1. What areas of new applications of PPMOF have the highest potential? (These can include extensions of Section 3 or other applications.)
- 4.2. What are the barriers to the implementation of these new applications?

5. Decision Making

- 5.1. How is the engineer/contractor typically involved in the decision to use PPMOF?
- 5.2. What factors considered in analyzing possible use of PPMOF?
- 5.3. What are the key criteria used to make the decision?
- 5.4. How is preplanning involved in the decision making process?
- 5.5. Who makes the decision to use PPMOF?
- 5.6. How is the decision made?
 - 5.6.1. At what stages in a project are decisions made most successfully?
 - 5.6.2. How does PPMOF affect preplanning?
 - 5.6.3. Are there flexibility issues?
 - 5.6.4. How do you determine the level of PPMOF?
 - 5.6.5. Does your company have a specific decision making process for the use of PPMOF?
- 5.7. What are the best practices in assessment and decision-making regarding possible use of PPMOF?
- 5.8. Other key considerations or aspects of the decision making process

6. Information requirements and flow using PPMOF

- 6.1. How have new technologies affected the flow of information between the key players? (Such as internet, intranet, EDI)
- 6.2. What level of information exchange is required for a PPMOF project?
 - 6.2.1. Are there security issues?
- 6.3. Are there standards for information exchange?
- 6.4. Coordination needs
 - 6.4.1. How is coordination handled in general between the owner, contractor, designer, fabricator, and/or supplier?
 - 6.4.2. How is structural design handled for loading and human access considerations during different phases of the project? (Fabrication, transport, rigging, connection, testing, operation, maintenance)
 - 6.4.3. What requirements are there for tracking the configuration, weight and center of gravity for each component?
 - 6.4.4. (Modularization only) How are process system and utility system (e.g., cooling water, compressed air, drain, electric power) coordinated for independent testing and operation of modules? (Coordinating these systems requires tracking loads, system completeness within assemblies, and interfaces between assemblies)
 - 6.4.5. (Modularization only) How is coordination handled for the process control system design for distributed control within each assembly or module and essential centralized monitoring and control? (Coordinating these systems requires manual analysis of distributed control functions and ability to satisfy requirements for centralized monitoring and control)
 - 6.4.6. What are the requirements for materials management activities through the life of the project? (From initial definition of requirements through procurement, supplier technical information, expediting, fabrication, factory testing, and delivery)

- 6.4.7. How is progress monitored during fabrication, assembly, testing, transportation, and startup?
- 6.5. What possible methods knowledge is required for the use of PPMOF?
 - 6.5.1. (Modularization only) What level of scope is required of a module? Is it tested and operated at the fabrication facility
 - 6.5.2. What considerations for configuration and weight are required to allow use of specific methods for transport, setting, and connection?
 - 6.5.3. What operations are required to fabricate, assemble, test, load, and transport units?
 - 6.5.4. Are there required fabrication tolerances to allow efficient field connection?
 - 6.5.5. (Modularization only) What are the preferred sequences for module setting, connection, and start-up?
 - 6.5.6. What changes in design requirements related to operational safety and maintenance are considered?
- 6.6. What are the possible component information and attributes required?
 - 6.6.1. (Modularization only) What are some examples of possible component systems? (Systems and members; process equipment such as pumps, compressors, heat exchangers; piping systems and components; electrical systems including equipment, raceway, and cables, and control systems)
 - 6.6.2. What are the technical attributes of components? (Function and capacity, design criteria and calculations, weight, size, center of gravity, utilities and services required, access to install and maintain, technical data from supplier describing operation and maintenance)
 - 6.6.3. Attributes related to fabrication, assembly, installation, operation, or maintenance; sequence, access and workspace, handling,
 - 6.6.4. How is quality control handled for components? (Documentation from design, fabrication, installation, and testing; materials certification; quality problems and their resolution)
 - 6.6.5. How is planning and progress monitored regarding attributes? (Including links with the construction plan, expected production and productivity values, links with other activities, schedule, cost, status)
- 6.7. Other considerations for information requirements

7. Contracts/Project Delivery

- 7.1. What types of contracts are typically used?
- 7.2. How is payment made?
- 7.3. What project delivery method is typically used? (Turnkey, DB/EPC, EPCM, DBOO, DBB, Maintenance)

8. Safety/Legal Issues

- 8.1. How does the use of PPMOF affect safety?
- 8.2. Local and site permitting (impacts on time and cost)?
- 8.3. Proprietary information retention?
- 8.4. Environmental restrictions?
- 8.5. How is insurance impacted?

SUPPLIER/FABRICATOR VERSION

1. Profile

- 1.1. Company/Project name
- 1.2. Type of industry
- 1.3. Type of work
- 1.4. Location
- 1.5. Contact information/People interviewed
- 1.6. How is PPMOF used the company/on the project?
- 1.7. What percentage of work is PPMOF?

2. Recent developments

- 2.1. Technology - Compared to 15 years ago, how have the following affected the use of PPMOF?
 - 2.1.1. Manufacturing Equipment
 - 2.1.2. Design (3D CAD, 4D CAD, etc.)
 - 2.1.3. Information technology (Internet, intranet, EDI, bar coding, etc.)
- 2.2. Economics
 - 2.2.1. How has the economy and labor situation played a role in the fabrication of PPMOF components? (Labor requirements, wages, plant layout, etc.)
- 2.3. Supply chain (Lean, JIT, etc.)
 - 2.3.1. Have advances in technology had an effect on material management and component tracking, and if so, how?

3. Future of PPMOF

- 3.1. What areas of new applications of PPMOF have the highest potential?
- 3.2. What are the barriers to the implementation of these new applications?

4. Decision Making

- 4.1. How are suppliers/fabricators involved in the decision to use PPMOF?

5. Information requirements and flow using PPMOF

- 5.1. How have new technologies affected the flow of information between the key players? (Such as internet, intranet, EDI)
- 5.2. What level of information exchange is required for a PPMOF project?
- 5.3. Are there security issues?
- 5.4. Are there standards for information exchange?
- 5.5. Coordination needs
 - 5.5.1. How is coordination handled in general between the owner, engineer/contractor, designer, fabricator, and/or supplier?
 - 5.5.2. How has technology influenced coordination issues?
- 5.6. What possible methods knowledge is required for the use of PPMOF?
 - 5.6.1. (Modularization only) What level of scope is required of a module? Is it tested and operated at the fabrication facility

- 5.6.2. What considerations for configuration and weight are required to allow use of specific methods for transport, setting, and connection?
- 5.6.3. What operations are required to fabricate, assemble, test, load, and transport units?
- 5.6.4. Are there required fabrication tolerances to allow efficient field connection?
- 5.6.5. (Modularization only) What are the preferred sequences for module setting, connection, and start-up?
- 5.6.6. What changes in design requirements related to operational safety and maintenance are considered?

6. Contracts/Project Delivery

- 6.1. What types of contracts are typically used?
- 6.2. How is payment made?
- 6.3. How does the project delivery method affect supplier/fabricator involvement?

Appendix B: Site Visit Reports

CENTRAL TEXAS IRONWORKS

Central Texas Iron Works* (CTIW) is a major structural steel fabricator with facilities headquartered in Waco, Texas. CTIW specializes in the fabrication of steel for industrial projects including petrochemical and power facilities. The company is part of the Herrick Corporation, a worldwide company involved in the design, fabrication, and erection of structural steel for industrial and commercial building projects. CTIW employs approximately 225 people and has the capability to produce 4,000 tons of steel per month. The company is an industry leader in the use of advanced fabrication equipment, CAD design and integration technology, and the use of electronic data interchange (EDI) for collaboration between project players. Recent implementation of new plant layouts and the incorporation of new technologies have allowed CTIW to address the current skilled labor shortage, reducing required labor by about two-thirds while approximately doubling productivity.

CTIW projects are mostly unit price driven, creating a need for optimization of operating efficiencies and increased productivity. The company recognizes the role of innovation and new technology in the reduction of unit cost. Technologies such as 3D CAD, database software, barcoding, the internet, electronic data interchange, and advanced fabrication equipment have all played a role in increasing market share. 3D CAD software has allowed company engineers to identify interferences and produce detail drawings for the fabrication equipment. Early collaboration between the engineering designers and CTIW allows for more efficient designs and communication of requirements. The process begins with the engineering firm sending neutral CAD design files to CTIW, who in turn develops detail drawings for connections and checks for interferences. (Neutral files are essentially stick models of the project, with each piece containing data on dimensions. The neutral files generally do not include connection details.) Through the use of 3D models, staff can check if beams conflict with handrails or other common interferences. This modeling helps to reduce field rework and increase quality. Once completed, detail drawings can be converted for use by the fabrication equipment.

The incorporation of advanced database technology allows the company to track material throughout the fabrication process. The application of bar codes assists in the tracking of materials once they have been completed and shipped to the project site or for further fabrication such as galvanizing. This allows project managers to track incoming material and provides a basis for payment. The database is open for the engineers and project managers to check the status of material. Mr. Harwell believes this feature is currently underutilized even given the high potential for increasing efficiency and reducing project costs.

* Please note that the trip report for CTIW does not follow the questionnaire format due to the timing of the report prior to finalization of the questionnaire format. The rest of the reports follow the final format.

The internet and electronic data interchange has allowed CTIW to receive design files for projects from engineering firms. High-speed electronic access has also allowed transfer of files to other Herrick facilities such as the V.S. Thai Herrick fabrication yard in Bangkok, Thailand. The internet has allowed CTIW to work on projects involving partners throughout the world. One current challenge with the use of the internet is the capability of the engineering firm to receive large electronic files. CTIW often receives the computer files electronically but returns the updated files via hard copy because the engineering firm does not possess the capability to receive the large files. Standardization of electronic file types and increasing file transfer abilities are potential areas of future improvement. Beyond the high technology in the office, CTIW has also installed advanced fabrication equipment throughout its facilities. Computer controlled cutting, drilling, punching, and other fabrication equipment uses the computer files made possible through the company's CAD and internet capabilities to fabricate parts. Equipment operators can call up a specific component from a computer file and load it into the machine. The machine then uses the file to identify where to punch a hole or cut a shape. This technology is a vast improvement over the old method, which used hand-drawn cardboard templates for each individual piece. The result has been increased productivity and efficiency.

The CTIW facility is separated into design offices, outdoor staging and fabrication, and indoor fabrication. The layout for these facilities and the equipment operating within all reflect the philosophy of reducing unit cost by increasing efficiencies and productivity. The design offices contain 6 CAD workstations, networked with approximately 40 additional remote locations, and several large plotters for the production of hard copy design drawings. These offices receive the neutral files from the engineering firms and create the 3D CAD models with the connection details. The company has a file transfer protocol (FTP) site to which the neutral files are sent. After the detail drawings are drafted, production estimates are made and foremen receive work packages for their crews. All the information is coordinated on a central database located on the company computer server.

The CTIW facility has a large outdoor laydown yard for the storage of materials and some fabrication. The entire area has been designed for forklift access, the primary method of transporting and manipulating material. The forklifts are more maneuverable and versatile compared to overhead cranes. Safety also is improved since loads are kept lower to the floor and do not travel over work areas. Where in the past a single crane was used to transport one piece at a time across the shop floor, multiple forklifts can enter and exit from a variety of points, increasing efficiency of movement. Activities that were previously done inside such as punching and drilling have been moved to satellite sheds in the outdoor yard, freeing up workspace indoors and reducing overhead. The facility is not air-conditioned.

Raw material is stored outside and is generally grouped by size. Color codes on the tips of girders identify material grade, while writing on the pieces denote flange width, material weight per unit length, and overall length. The material is brought in from suppliers from as close as Texas to as far as the east coast of the US. The raw material orders require a long lead-time and minimum order sizes. Lead-times vary from 6-14 weeks, depending on the market and communication efficiencies. Advances in coordination resulting from EDI and the internet may help to shorten lead-times. CTIW tries to order just for specific projects, but at times is required to order additional material

to fulfill minimum requirements or to maintain inventory. Besides the raw material supplier, CTIW also has the option to purchase from steel warehouses, but at a higher premium. This becomes an important consideration during the project bidding process.

Punching, coping, and drilling of material are accomplished in satellite work sheds located in the raw material laydown yard. An area foreman coordinates the jobs for the equipment operators. Forklifts deliver material to the sheds, while sliding racks and conveyor systems move material from one shed to another. An operator programs the each machine to drill, cope, or punch holes for plates, angles, or fittings. Each computer uses the converted CAD files from the design office database to guide the machine tools. Rotary encoders measure the position of each piece and help the machine reference the physical piece to the virtual design file. One potential source for error with the encoders occurs if the raw material contains dirt or an irregular camber that adds error to the encoder reading. Overall, however, through the use of computer controlled machinery and material management, higher quality and reduced rework is achieved.

Besides increasing efficiencies by locating these facilities outside, CTIW recently purchased a new drilling machine that produces holes faster in the pieces than the traditional methods. The new drilling machine, with its multiple bits and constant cutting action, reduces time required to produce multiple holes of varying dimensions, thereby increasing productivity.

After material has been moved through the satellite sheds, a forklift operator organizes the material into jobs in another section in the outdoor laydown yard. From this location, material then moves inside for further fabrication if necessary.

The indoor facility is divided into separate areas according to the type of product to be fabricated. Sections are devoted to beams, columns, connection material, and specialty items. Specialty items include custom pieces such as handrails. Space is given around each work area for forklifts to deliver and manipulate material. Overhead cranes are also available, but used less because of the increased efficiency of the forklifts. Besides the space for access via forklift, the indoor space can be accessed from the outside through many large doors. These concepts of material flow and access are similar to the lean concepts used in new automobile manufacturing facilities.

The fabricating equipment inside also operates off of the computer files from the central network. Computer controlled equipment includes a plasma plate cutter, angle machine, punching equipment, and other equipment. CTIW is in the process of adding a second plasma plate cutter to increase production capacity. Other indoor facilities include sand blasting and painting areas. Once a component has reached a certain point in the fabrication process, it receives a bar code label and a permanent die-stamped tag. The primary purpose of the label is to track the material once it leaves the fabrication facility. The component can be shipped to another facility for further processing such as galvanization at a CTIW partner's plant in Houston. The bar code is also used to provide information on materials received at the final construction project site.

Beyond the efficiency and productivity issues, management also stressed other factors that influence the fabrication process. Organizational and partnership issues play a significant role. CTIW has formed alliances with owners like Shell to be a provider of steel for petroleum facilities. Through this partnership, integrating the owner, engineer, contractor, fabricator, and supplier can eliminate redundant work processes. Standardization of material tracking and computer file transfer can improve

communication, reduce rework, improve schedule and cost control, increase quality, and improve many other project management tasks. Legal considerations also influence standards, since owner, contractor, and fabricator standards may differ. Decisions on which standards will be held accountable need to be considered.

Future needs for the industry include the increased use of EDI to reduce printing and improve communication efficiencies. Companies should seriously commit to EDI. Companies should also place a higher priority on research and development to improve the process. There is a need for better calculation of total installed cost to assist in measuring performance. Better dissemination of best practices throughout the industry will also help to advance the industry.

While CTIW is not often directly involved in pre-assembly work, many of the innovative and advanced practices could be easily applied to projects involving pre-assembly and modularization. The level of coordination of the owner, engineer, contractor, fabricator, and supplier that has been achieved by CTIW is directly transferable to pre-assembly and modularization. The innovative level of technology, especially the use of the internet, EDI and material tracking, has proven to increase efficiencies.

ELI LILLY CO. INC.

Overview

The main purpose of the initial interview with upper management was to gain an overall perspective of how Lilly is involved in modularization and the processes and factors influencing implementation. The individual interviewed is seen as the leader within Lilly who has championed the use of offsite modular construction for appropriate Lilly capital projects.

The purpose of this meeting was to gather information at the project level regarding the use of modularization on Lilly capital projects. One of the project managers has experience with past Lilly modularization projects, specifically a recent facility in Egypt. He is acting as a consultant to Mr. Bowman on the current Indianapolis project.

The current project in Indianapolis is a pharmaceutical manufacturing facility designed to produce a finished product from bulk materials brought in from other facilities. The equipment has been designed to produce one product at a time, but has the flexibility to produce up to five different products. Processing areas will be sterile and must be separated from the wet systems to prevent contamination in the event of leakages or breakdowns. Therefore, wet systems have been placed in the basement and are being constructed via stick built methods. The sterile main floor and the air handling units on the second floor are constructed in 12'x30'x10' modules, with 52 main floor modules and 29 second floor modules. The module constructor, Pharmadule (www.pharmadule.com), built the modules in Sweden and is installing them in Indianapolis. Construction of the \$85 million facility began in July 1999 and is expected to last 16 months. Preplanning began in October 1998, with the feasibility and decision to modularize in February 1999. The Lilly staff consisted of six dedicated people initially, with 20 total eventually, including engineering and maintenance. Construction of modules began when ground was broken for the basement, allowing for parallel construction to reduce project schedule. The peak onsite workforce has been 85 vs. an estimated 200 for stick built.

Jacobs Engineering handled the engineering and construction management for the project. Jacobs was also responsible for the interface between the modules and the stick built areas, including wet connections. Contracting was handled through multiple primes. Work to install the modules was estimated at 30,000 hours, with an additional 30,000 for the basement and support building.

Cultural change was a large part of the construction process. Contractors and project team members who initially doubted that the offsite modular construction concept could succeed, realized the benefits once the modules were delivered. Cultural change occurred within Lilly engineering staff. With the use of modularization, the emphasis was placed on repetition of design rather than innovation of design. The culture of change orders for the project in general was also altered. Since the modules are built off site with limited access, the customer is not as inclined to ask for changes. The client accepts the work because it functions and meets the requirements. The reduction in the opportunity to make changes results in fewer unnecessary changes.

One key concept identified through the interview was that the Lilly project team felt that the use of modularization forces early planning, constructability, alliances, and

many other similar CII best practices. While this concept is very powerful, substantiation would be required before claims could be made.

1. Profile

1.1. How is PPMOF used by the company/on the project?

Lilly uses modular concepts for the construction of some of its pharmaceutical manufacturing facilities. These facilities include bulk chemical processing, dry products, and wet products such as insulin. Some facilities include clean rooms and extremely specialized equipment. There are only a select few engineers, contractors, and suppliers capable of meeting Lilly's needs. Most of them are on a preferred list for Lilly.

1.2. What percentage of work is PPMOF?

Bill Smith estimates that 5-10% of Lilly's capital goes into modular projects, with an increasing trend. As far as percentage of individual projects that are modularized, exact numbers were not given. For the Indianapolis project, the above ground sterile and HVAC areas were modularized, while the basement and the support building were conventionally constructed.

2. General Questions regarding PPMOF

2.1. What are the drivers?

The use of modularization for these projects is mainly driven by business needs. Timing capital improvements with Food and Drug Administration (FDA) approval is critical. The schedule compression permitted by the use of modularization enables Lilly to make decisions later in the process while decreasing time to market. One critical factor is the desire to only build what is needed. Early construction decisions create greater risk. Cost is a factor, but not as big as schedule and business requirements. The increased safety of modular construction is also a factor in the process, since a majority of work is done less than 14 feet in the air in a fabrication shop environment, rather than a construction site environment.

2.2. What are the project objectives and how do they influence the use of PPMOF?

The objectives of the project are to meet the business needs of Lilly. These include building only those capital facilities that will be needed to meet short to medium term facility capacity requirements, and meeting the schedule as dictated the business requirements.

2.3. What are the benefits?

Benefits include reduced risk through later decision making facilitated by schedule compression. Only the facilities that are needed are built. Some cost benefits have been realized compared to stick built options. Initial cost analyses show modular as a more expensive option, but inaccurate stick built estimates of cost and duration, as well as net present worth considerations makes the modular option more economically viable.

Increased safety due to decreased height of work and increased quality due to controlled manufacturing conditions were also identified as benefits. Modularization can be useful on environmentally sensitive sites, since the site can be remediated while modules are constructed. Also in some cases it may be

possible to be constructing modules offsite, while pursuing environmental permits for the construction site.

Lilly does not believe their cost comparisons are worth using, typically they have done an initial comparison, before the stick/modular decision is made, then the project has been done modular. During the life of the project there have been scope changes (often wide ranging and difficult to track, but just driven by the greater level of knowledge that is gathered as the project gets into more detail). At the end of the project, the actual modular cost is then higher than the estimated stick cost, which at that point we know was inaccurate. They have not invested the time to go back and rationalize the estimates.

2.4. What are the impediments?

Impediments to the use of modular construction tend to be more related to business and cultural issues rather than technical. Traditional impediments such as transportation requirements have not been a large problem for Lilly. Lilly has found that shipping companies are experienced in handling large loads and has had success in Ireland, Egypt, China, and now in the US. Building permitting was not a major issue. A third party with a professional engineering license and approved by the State of Indiana handled permitting and monitoring of module construction in Sweden.

The main impediments for Lilly are dealing with cultural issues within the company and the construction community. Many experienced project personnel are mostly familiar only with stick build. Initial beliefs were that modular could not beat the quality and cost efficiency of stick built, especially in the US. Since historical data was not available to reduce resistance, the implementation required upper management support and a champion to bring about the change. Management dictated the use of modular and once the projects were proven successful at different stages, team members and contractors were convinced.

Other challenges include flexibility, risk, coordination, and preplanning issues. Flexibility issues are also an impediment, but more from the equipment standpoint rather than modular restrictions. Equipment requires in some cases longer lead times than the actual construction, thereby constraining decisions. These long lead times require negotiated contracts for equipment rather than open bidding. In order to improve flexibility during construction, the basement was stick built, allowing flexibility of routing utilities to the modules.

Because of the compressed schedule, some modules must be built at risk prior to permitting. Coordination requirements are increased due to the design requirements and multiple construction sites. Detailed designs of connections, finishes and architectural aspects are required for module construction. Multiple construction sites required team members to be able to access and distribute information globally. Lilly is responsible for coordinating all parties involved. Preplanning requirements are increased in order to determine the feasibility of the use of modularization.

3. Recent Developments

3.1. Technology - Compared to 15 years ago, how have the following affected the use of PPMOF?

3.1.1. Equipment

Lead times for facility equipment dictate the critical path of the project. These times can be as great as 55-60 weeks. Lilly has a list of preferred suppliers through which it negotiates contracts. Negotiation helps to further expedite the process and is faster than open bidding. Given the relatively low number of suppliers able to meet the quantity of modules Lilly requires, the preferred list method is adequate. Lilly is responsible for procurement.

3.1.2. Design (3D CAD, 4D CAD, etc.)

3D design was not used for the modular projects. 3D animations have been used to help operations staff to visualize the finished product. Drawings were completed using 2D CAD, which was found to be adequate. The use of 2D CAD was enough given that the modules were each joined along a 2D plane, simplifying drawing requirements. Lilly has used 3D CAD successfully as the primary design tool on another modular project where the module supplier was Jacobs Applied Technology.

3.1.3. Information technology (Internet, intranet, EDI, bar coding, etc.)

The project teams use Lotus Notes to communicate between the sites. Mr. Bowman also recorded progress on the project with a web camera, recording one picture per hour from ground breaking to dry-in. The pictures will be used for a time-lapse video of the project.

3.2. Economics

3.2.1. How has the economy and labor situation played a role in the decision to use PPMOF?

Lilly has not received any problems from organized labor as a result of their decision to outsource the work for their projects. With the low levels of unemployment in the US and large number of construction projects, many local contractors are already stretched out. If the economics were to change, opposition could potentially increase.

4. Future of PPMOF

4.1.1. What areas of new applications of PPMOF have the highest potential?

In the future, Lilly would like to build the decision process into their preplanning “profiling” for the project. This would help the team determine the feasibility of modularization.

Other owners are interested in Lilly’s work, namely Merck and Dupont. There is also the potential for cross industry learning with companies in the chemical and petroleum industry.

4.1.2. What are the barriers to the implementation of these new applications?

Acceptance of modularization and other cultural issues will continue to provide obstacles. However, Lilly modular successes are proving to reduce these barriers. This will continue with the growing number of successful projects and historical data.

5. Decision Making

5.1. What factors considered in analyzing possible use of PPMOF?

Business factors are the main considerations for deciding to use modularization. Schedule needs, project scope and process issues factor into the decision. Patent issues also play a role in determining facility life cycle and flexibility requirements.

5.2. What are the key criteria used to make the decision?

Business factors including schedule needs, project scope, and process issues are key criteria.

5.3. How is preplanning involved in the decision making process?

Lilly uses extensive preplanning for the evaluation of its projects. The process, called “profiling”, takes into account business requirements and establishes a conceptual plan. Many Lilly representatives are involved in the process including marketing, manufacturing, and engineering. The profiling process determines the scope of the work, and project delivery method.

For the Indianapolis project, the Lilly team began a feasibility analysis to consider the modular option. The analysis initially showed that modular construction would be 10-20% more per square foot compared to stick built. The analysis was difficult to quantify due to lack of historical data and the cultural bias of the project analysts. Most of the members were partial to stick built because that is what they were familiar with. It was also difficult to estimate schedule impacts and net present worth savings resulting from modular construction. As a result of these considerations, the study was only 85% complete, when upper management, driving the decision to modularize, decided to terminate the study. This decision was based mainly on the results of recent simpler modular projects in China and Egypt. These projects were shown to be cheaper and faster than originally estimated, and the stick built projects showed a tendency to be underestimated.

5.4. Who makes the decision to use PPMOF?

Lilly makes the decision to use modularization based on the profiling process and the efforts of the champion.

5.5. How is the decision made?

5.5.1. At what stages in a project are decisions made most successfully?

Decisions by Lilly are made early in the planning process, usually during the project profiling process.

5.5.2. How does PPMOF affect preplanning?

PPMOF decisions are made during preplanning, as the decision affects many aspects of scheduling, cost, engineering, permitting, and transportation issues. This process is not presently carried out formally, although there are plans to implement in the future.

5.5.3. Are there flexibility issues?

Flexibility issues are generally related to the process equipment rather than the fixed scope associated with modularization. Since equipment lead-times are sometimes longer than the module construction, equipment procurement actually dictates flexibility. For long-term flexibility issues, Lilly believes that the modular design may provide interchangeability and

expandability. Plants may also have the capability of disassembly, relocation, or salvage, depending on future needs.

For the Indianapolis project, the facility was designed to have the capability to produce five different products. This would allow the facility to change its production according to needs. The plant has also been designed for expansion, with knockout walls and standard modules. For flexibility during construction, the engineers determined the main routing of utilities in the basement, while the contractors were responsible for the detailed routing. Given the generous dimensions of the new basement, the contractors were able to work together to plan the details of routing, with the mechanical subcontractor as the lead.

5.5.4. How do you determine the level of PPMOF?

For the Indianapolis project, schedule helped to dictate the level of modularization. The basement and support building, which were stick built, were constructed in parallel with the modules. Parallel construction allowed a reduced schedule. Had the project been completely modular and carried out by the single supplier, the schedule would have been increased.

5.5.5. Does your company have a specific decision making process for the use of PPMOF?

Lilly has in the past done some feasibility studies of the use of modular vs. stick. Mr. Smith has found that the level of detail for investigation should be low and mostly subjective. Extensive studies take large amounts of time and often the historical data is not available to the level of detail required for accuracy. In the past, Lilly has found that a champion of the cause and an open-minded team is enough to make the decision.

6. Information requirements and flow using PPMOF

6.1. How have new technologies affected the flow of information between the key players? (Such as internet, intranet, EDI)

Computer connections have allowed Lilly to work with project team members on a global basis, with team members transferring information via the internet.

Electronic technology speeds up communications, and eliminates the need for filing clerks to receive, file and distribute documents to the project team members (important with the present day lean approach to engineering). Use of technologies that allow near real time access to documents (including drawings) by all project team members, from their desktop PCs (and laptops while travelling) have been particularly helpful. Barriers to speed can be the traditional in-house "management approval procedures" still followed by some engineering firms. Use of Lotus Notes within Lilly has been an important way of standardizing project management tools such as metrics reporting and change control.

6.2. Coordination needs

6.2.1. How is coordination handled in general between the owner, contractor, designer, fabricator, and/or supplier?

Lilly handles the coordination of the team members, both internally and with the other contractors involved on the projects. Besides the electronic communication, quarterly meetings were held involving all parties to coordinate schedule and handle project issues. For coordination on the site, work on module placement was done from the inside out to reduce tolerance problems.

7. Contracts/Project Delivery

7.1. What types of contracts are typically used?

For local contractors, Lilly bids out the work on a lump sum basis. For other contracts, such as with Pharmadule, the work is negotiated as a lump sum. Some of the reasons for this include the limited number of contractors capable of handling large modular projects and the niche characteristics of the market.

7.2. How is payment made?

For local contractors, it is monthly against an invoice, based on % completion.

For Pharmadule it is a pre-planned payment schedule of 6 x 15% payments and 2 x 5% payments at agreed milestones eg. With order, at start of fabrication, when first modules delivered, when last delivered, etc....

7.3. What project delivery method is typically used? (Turnkey, DB/EPC, EPCM, DBOO, DBB, Maintenance) EPCM

US STEEL FAIRFIELD WORKS

Overview

The US Steel Fairfield Works is a steel manufacturing facility producing sheet products and seamless pipe for use as feed stock in many industries. Uses for piping products include piping for the oil and gas industry, fluid transmission applications, and for construction applications. Sheet products have many potential applications, from roofing to automobile fenders to kitchen pots.

Regardless of the material produced, the entire process is driven by a blast furnace that produces molten iron for several smaller steel producing vessels in Fairfield's Q-BOP facility. The Q-BOP mixes the molten iron with various metals via computer control to create different grades of steel. Molten steel is then transferred from the vessels to two continuous casting machines that use molds where either slabs or rounds of steel are cast. Slabs go through an extensive number of machines and processes to become sheet products in coil form. The rounds are processed into piping. Surfaces are cleaned and finishing is done according to customer specifications. The entire process is highly computerized and in some cases automated. There are many large pieces of equipment and control facilities involved in the process. Environmental, power and water treatment requirements further the need for extensive systems. The result has been improved safety, productivity, and an increase in the grades of products produced.

Since the output of the facility depends on the continual operation of the equipment, capital improvements, maintenance, and upgrades are a challenge to schedule.

Installation of equipment and construction activities must be done as efficiently as possible without endangering workers or adversely impacting production. Outages must be kept to a minimum and design for start-up is critical. For these reasons, US Steel has chosen to use prefabricated, pre-assembled, and modular concepts for many of its installation and construction activities.

PPMOF Examples

PPMOF is used extensively for US Steel projects, especially in the equipment area. Some of the examples include:

- Baghouses for cleaning exhaust
- Galvanize dipper for steel sheeting
- Q Bop furnace ventilation
- Control buildings for furnace and manufacturing equipment
- Caster mold assemblies for slabs and rounds
- Tundish cars for delivering molten steel into molds
- Caster, cut to length Torch assemblies
- Cooling towers
- Coal injection pipe bridges
- Material conveyors
- Civil elements such as concrete pipe and manholes

1. Profile

- 1.1. Company/Project name US Steel (a unit of USX)
- 1.2. Type of industry basic steel
- 1.3. Type of work manufacturing
- 1.4. Location Fairfield, Alabama
- 1.5. Contact information/People interviewed see end of report
- 1.6. How is PPMOF used by the company/on the project? Equipment, structures, ventilation, environmental facilities
- 1.7. What percentage of work is PPMOF? The estimated percentage of PPMOF depends on the nature of the project. A majority of equipment arrives pre-assembled. The percentages decrease for projects involving more civil work. Exact numbers were not given, but an overall estimate was 30%.

2. General Questions regarding PPMOF

2.1. What are the drivers?

The main driver on most projects is design for start up to reduce shutdown time. The more work that can be completed offsite will help to maintain production levels of the mill. Other drivers include safety considerations, outage schedules, and scope definition. US Steel believes that PPMOF provides reduced risks of uncertainty during outages. Since equipment is tested and tolerances for installation are checked prior to onsite installation, outage time and impact to production is

potentially reduced. Training of workers can be done at the offsite fabrication facility, where experts are available to answer questions. Testing at the fabricator allows bugs to be worked out. This reduces the need to conduct rework or field fitting.

2.2. What are the project objectives and how do they influence the use of PPMOF?

Objectives depend on the project. Overall, the main goal is to accomplish project objectives without compromising safety or production. Some objectives include upgrading to meet environmental standards, increasing production capability, maintaining facility infrastructure or improving safety.

2.3. What are the benefits?

The main benefit is the improved startup performance. PPMOF systems can be tested and debugged prior to installation. Other claimed benefits include increased quality, reduced onsite congestion, higher craft productivity, and cheaper labor rates. Schedule compression, decreased overall cost, and increased safety due to ground level work are also considered potential benefits. Specific projects provide certain benefits. For example, precast civil piping structures for the wastewater systems have reduced the need for expensive shoring and decreased safety risks during installation. Other benefits include the reduced need for lifting equipment on site. During the installation of baghouses on one project, a single lift was required for each module from truck to final placement. This reduced movement of materials and components decreased costs associated with lifting equipment.

2.4. What are the impediments?

Increased engineering costs and preplanning are the main impediments identified. Other barriers include lack of vendor or contractor capacity and/or experience in the use of PPMOF. The extensive testing requirements for equipment also may exceed the vendors general experience.

3. Recent Developments

3.1. Technology - Compared to 15 years ago, how have the following affected the use of PPMOF?

3.1.1. Equipment

The ability to package equipment for steel production using PPMOF methods has improved to construction process. Equipment can be tested and verified using PPMOF, allowing for a more economic project life cycle overall.

3.1.2. Design (3D CAD, 4D CAD, etc.)

Engineers working with US Steel on modular projects have used 3D CAD. Constructability was evaluated using the models. Modeling helped the project team plan construction activities so the plant operation impact would be minimized. This involved checking where plant workers would be located and where possible conflicts with furnace operation might occur.

3.1.3. Information technology (Internet, intranet, EDI, bar coding, etc.)

Email and the internet allows drawings to be transferred electronically. Officials claim this has reduced shipping costs (such as FedEx deliveries), turnaround time, and travel costs. Exact numbers were

not available, but US Steel reps mentioned that there was a clear difference. The use of email facilitates the involvement of the whole team, since the same message can be sent to all the team members. Email also provides documentation of communication, furthering accountability. Some drawbacks were identified. The use of email often requires quicker decisions given the speed of the communication. It appears that methods such as phone calls were expected to take a longer time to respond. Other issues include incompatible file types. It is believed that advances in technology will eventually eliminate these issues.

The internet has also been used to locate equipment. In one example, US Steel representatives were able to locate large specialized carts for hauling molten iron. The owner was in Australia and US Steel reps in Alabama were able to obtain information and photographs over the internet. While such a large purchase will still require an inspector to travel down to view the equipment, the internet has reduced travel and communication costs. The global marketplace online also helped with locating the ladle cars, making advertising more accessible.

Bar coding is used in the warehouses during the final storage of raw material prior to shipping. Workers carry scanners on the forklifts that are used for transporting material. Each steel coil has a bar code and as does each location in the warehouse. Workers scan the coil and the location bar codes and a database collects the information.

3.2. Economics

3.2.1. How has the economy and labor situation played a role in the decision to use PPMOF?

The current shortage of skilled labor and the reduced cost of shop labor over field workers are both economic considerations affecting the usage of PPMOF.

4. Future of PPMOF

4.1.1. What areas of new applications of PPMOF have the highest potential?

US Steel would like to continue maximizing its use of PPMOF concepts throughout its new construction and maintenance projects.

4.1.2. What are the barriers to the implementation of these new applications?

The increased engineering and planning requirements are barriers to the increased use of PPMOF. These costs must be justified to the owner. Other barriers include the lack of experience in the industry, which presents a learning curve for project participants. US Steel believes that partnering and turnkey style projects have helped to reduce problems associated with barriers and impediments to PPMOF. In their experience, these contractual setups have led to better start-ups.

5. Decision Making

5.1. How is the owner involved in the decision process?

As a project team member, US Steel representatives are directly involved in the decision to use PPMOF.

5.2. What factors considered in analyzing possible use of PPMOF?

Factors such as schedule, cost, site conditions, pretesting requirements, and safety are considered in the decision process. Outage scheduling is a critical component of the decision. Since PPMOF has the potential to facilitate shorter install times and less impact on operations, most equipment upgrades and maintenance involve these methods.

5.3. What are the key criteria used to make the decision?

Key criteria include cost, schedule, safety, and impact on production.

5.4. How is preplanning involved in the decision making process?

Thorough preplanning is required to select the correct alternative. In some cases, representatives estimate from 3-15% of engineering is done prior to authorization. This allows thorough alternative analysis and justification for appropriation.

5.5. Who makes the decision to use PPMOF?

The project team makes the decision to use PPMOF.

5.6. How is the decision made?

5.6.1. At what stages in a project are decisions made most successfully?

It is suggested that successful decisions to use PPMOF are made early in the project, during conceptual design.

5.6.2. How does PPMOF affect preplanning?

US Steel believes that PPMOF increases preplanning substantially. Thorough planning and analysis is necessary to justify the use. Exact increases were not available.

5.6.3. Are there flexibility issues?

Lack of flexibility can be an issue on PPMOF projects. In the past, the contractor has absorbed minor scope changes, since the original lump sum had cost buffers built in. Flexibility is not a concern for US Steel during installation since it is in their interest to minimize installation time. US Steel prefers components to be tested and finalized before onsite work is conducted.

5.6.4. How do you determine the level of PPMOF?

The level of PPMOF is determined by how close it meets project objectives.

5.6.5. Does your company have a specific decision making process for the use of PPMOF?

While US Steel does not have a specific decision making process.

5.6.6. What are the best practices in assessment and decision-making regarding possible use of PPMOF?

A thorough methodology for comparison of conventional methods versus PPMOF would be a best practice for assessment and decision making. Assessment factors would potentially include safety, cost, schedule manpower considerations.

6. Information requirements and flow using PPMOF

6.1. How have new technologies affected the flow of information between the key players?

US Steel believes that the internet has improved drawing and other information exchange. Information flow is potentially faster and documentation is improved.

- 6.2. What level of information exchange is required for a PPMOF project? At which phases?

A major portion of information exchange takes place during the conceptual design.

- 6.3. What experience and knowledge is typically required by the owner of the contractor/engineer?

For US Steel projects, the contractor or engineer needs to understand construction and fabrication issues associated with the operation of the steel mill. These factors influence the requirements for start-up and coordination during plant operation. US Steel understands that for some engineers and contractors, the concepts of PPMOF are new and a learning curve is expected.

- 6.4. Are there security issues?

No security issues were reported related to the use of electronic exchange.

- 6.5. Are there standards for information exchange?

Email and CAD type files are standards for information exchange. While there are some conflicts with file types, future technology hopefully will reduce the current difficulties.

- 6.6. Coordination needs

- 6.6.1. How is coordination handled in general between the owner, contractor, designer, fabricator, and/or supplier?

Communication protocols are used at the team level to coordinate.

Daily meetings with team players take place during the project. A dedicated staff member handles scheduling and schedules are in some cases updated twice a day.

7. Contracts/Project Delivery

- 7.1. What types of contracts are typically used?

Contract types include partnerships or bid as fixed lump sum. Partnerships are generally used when outage schedule is unknown or conditions result in poor scope definition. Activities such as excavation may be difficult to place exact cost values on. Projects can be bid as a fixed lump sum when scope and schedule are well defined.

- 7.2. How is payment made?

Payment is made by % units, by milestones, or by work progress.

Milestones can include reception of raw materials in shop, fabrication completion, testing completion, and final assembly.

- 7.3. What project delivery method is typically used? (Turnkey, DB/EPC, EPCM, DBOO, DBB, Maintenance)

While turnkey has been used, costs are generally higher than traditional methods. Design build has been more effective for projects.

MCABEE CONSTRUCTION, INC.

Overview

McAbee Construction is an industrial contractor involved in the fabrication of vessels, piping, modular units, and sheet metal for projects such as chemical facilities, power plants, refineries, and pulp and paper mills. The company's union workers perform approximately 1.5 million manhours of work per year and the company claims an OSHA Recordable Rate of 2.5 in 1999. The company also claims certification in ASME codes for all fabrication activities and a 0.8% weld rejection rate. The company's in-house engineers use AutoCAD and 3D software to produce 3D models of elements before fabrication. The company claims these computer technologies have helped to reduce fabrication rework and problems with field fitting. Automated and computer controlled equipment also have the *potential to increase efficiency of fabrication and production capacity*. Through the increased production capacity, McAbee claims it has been able to retain the workers the machines replace. Depending on customer requirements, fabricated components can be tested and verified through erection onsite at McAbee's facilities in Tuscaloosa. From there, components can be transported by truck, rail, or barge. McAbee can mobilize its workforce and has its own fleet of cranes for erection.

The modular division of McAbee claims experience in 38 states and 17 countries. McAbee stresses the use of modularization whenever possible, and claims to have expanded the extent of modularization in projects beyond the level offered by competitors. The benefits cited are numerous, including decreased site exposure, increased safety and quality, reduced manpower and project costs, highly trained, consistent craftsmen, and reduced bad weather days. McAbee claims only two bad weather days in the past 20 years. They believe this is a direct result of the controlled fabrication areas and reduced site exposure. Modules typically take approximately 13-16 weeks each to produce. During one project, McAbee says it was fabricating 27 modules in shop and turned out about 1.5 modules a week. Modules have varied from decaffeinated coffee flavoring units to facilities designed for converting ICBM liquid rocket fuel into marketable base chemicals. McAbee has experience with exotic materials such as titanium and advanced requirements such as lethal containment.

Modular Example

One particular project provides an example of the benefits typically associated with modular construction. A Catalyst Plant built for BP Chemicals was designed, fabricated, verified and assembled by McAbee Construction. The plant consisted of fourteen modules with a footprint of 52' by 52' and a height of 110'. The fourteen modules made up three modular assemblies with a total weight of 770 tons. The facility included 17,000 feet of piping, 55,000 feet of wiring and 58 pieces of equipment.

The total project duration was 15 months from conceptual hand drawings to installation. Work began with hand sketches and flow charts of the processes involved. A project team conference, consisting of the owner, engineering firm, and McAbee, met to determine initial module concepts. The engineering firm provided the process design (P&ID's) for the project in March 1998, and one year later McAbee had the complete

drawings and details. Modules were constructed at McAbee's Tuscaloosa plant over a 3 month period. The size of the project dictated the need for a capital investment, by McAbee, whereby a 350 cubic yard concrete assembly pad was established. Modules were then assembled in the operational position, reviewed, and accepted by all project team members prior to shipment to the actual job site. Customer schedule requirements and limited availability of local labor, along with a desire to minimize the on site installation envelope, were the critical elements in deciding on this level of modularization. After acceptance, modules were shipped to the project site on the Texas gulf coast. Using a 350-ton conventional crane and a 400-ton hydraulic crane, the modular system was loaded onto special transport and shipped via barge. Once the erection process began at the site, the modules were reassembled in 8 days, ready to begin the owners commissioning process.

1. Profile

- 1.1. Company/Project name McAbee Construction
- 1.2. Type of industry Industrial
- 1.3. Type of work Chemical and Process facility construction
- 1.4. Location Tuscaloosa, Alabama
- 1.5. Contact information/People interviewed Harold Parker, Project Manager
- 1.6. How is PPMOF used by the company/on the project?

McAbee uses PPMOF concepts to construct chemical, power, steel casting, and other industrial facilities. This includes piping and vessels prefabrication, as well as pre-assemblies such as valve and equipment assemblies. McAbee also constructs modules.

- 1.7. What percentage of work is PPMOF?

McAbee performs both PPMOF work and stick work. Stick work includes earthwork, concrete and other areas where PPMOF is not applied. Approximately 15% of their work is PPMOF. The level of PPMOF on any one project can range from 15% - 100%, depending on the project.

2. Recent developments

- 2.1. Technology - Compared to 15 years ago, how have the following affected the use of PPMOF?

- 2.1.1. Manufacturing Equipment

Improvements in fabrication technology have potentially improved the process of building PPMOF items. McAbee has automated welding and cutting equipment that they claim increase safety, quality and production.

- 2.1.2. Design (3D CAD, 4D CAD, etc.)

McAbee is involved in the use of 3D modeling for inference checking, design coordination for operations and maintenance, marketing, and owner visualization. Savings in rework for field fitting are estimated at 3-5%. Designing in 3D has the potential to reduce conflicts and therefore reduces adjustments during installation. However, computer modeling is not seen as a substitute for firsthand knowledge and field experience. Modelers may need to be familiar with fabrication, assembly and operation in order to effectively model. Computer modeling may produce many alternatives that appear feasible on screen but are not efficient in the field.

2.1.3. Information technology (Internet, intranet, EDI, bar coding, etc.)

Email and the internet have provided opportunities for project team members to communicate more effectively. Messages are generally more brief and direct, as opposed to phone calls that take time to establish and longer to effectively communicate. Electronic communication is estimated to be cheaper than traditional phone or fax. Email also allows documentation of communication. Bar coding is used in the pipe fabrication shop to track production of pipe spools.

2.2. Economics

2.2.1. How has the economy and labor situation played a role in the fabrication of PPMOF components? (Labor requirements, wages, plant layout, etc.)

Current labor shortages, high field labor cost, and low field productivity all play a role in the implementation of PPMOF.

2.3. Supply chain (Lean, JIT, etc.)

2.3.1. Have advances in technology had an effect on material management and component tracking, and if so, how?

JIT concepts are applied throughout the process of fabrication and assembly. Raw material is only ordered and stored as needed. This is driven by tax considerations, customer desire for new materials, pricing advantages, and the minimization of inventory.

3. Future of PPMOF

3.1. What areas of new applications of PPMOF have the highest potential?

McAbee foresees growth throughout the industry, particularly in the power industry. Current increased demand for electrical services and plant shortages will drive the industry.

3.2. What are the barriers to the implementation of these new applications?

Industry culture and mindset may provide the largest obstacles. Engineers and craftsmen with little experience in the use of PPMOF are estimated to be less likely to accept the concepts. McAbee believes that few engineers are educated in the thought processes involved in prefabrication and modularization. For example, designing a 20' structural column into two 10' columns to allow shipping may not be intuitively obvious for designers. Structural design is not compromised provided connections and cross section are adequate. Similarly, craftsmen trained in stick construction may be slow to adopt the new methods, but advantages in safety and site conditions make this less of a challenge than overcoming the engineering mindset.

4. Decision Making

4.1. How are suppliers/fabricators involved in the decision to use PPMOF?

McAbee strongly encourages the use of PPMOF on projects. The company designs bids for optimal use of PPMOF as a selling point. The bids demonstrate the advantages of PPMOF and in some cases McAbee claims it has helped to win contracts. The decision to use it must be early, prior to engineering design.

5. Information requirements and flow using PPMOF

5.1. How have new technologies affected the flow of information between the key players? (Such as internet, intranet, EDI)

Email, the internet, CD's and 3D models have all been seen as improvements in the efficiency and effectiveness of information flow between team members. Email potentially allows quick and worldwide access to information. CD's containing drawings can take the place of expensive paper versions. 3D models can improve visualization and allow team members to communicate ideas more effectively.

5.2. What level of information exchange is required for a PPMOF project?

Information levels vary during the life of the project. At the initial conceptual design stage, McAbee works with the owner / engineer to determine constructability and modular concepts. Then P&ID's are provided by the engineers to guide McAbee in the detailed design of the modules. Beginning at 60% design completion, all team members meet to go over the design and insure requirements for operation, maintenance, construction, and any other team member considerations. Successive design review meetings are conducted as warranted.

5.3. Are there security issues?

Proprietary information is protected through secrecy agreements as part of pre-bid or contract requirements.

5.4. Are there standards for information exchange?

Some customers require specific computer drawing (ACAD) format to match their own systems or file requirements.

5.5. Coordination needs

5.5.1. How is coordination handled in general between the owner, engineer/contractor, designer, fabricator, and/or supplier?

McAbee project players use a team-oriented approach. Beginning at 60% design completion, representatives from all parties meet to review drawings and models to finalize layouts. Considerations for safety, operations, maintenance, optimal use of materials, and owner requirements are taken into account before final design.

5.5.2. How has technology influenced coordination issues?

3D modeling has the potential to improve visualization and communication of ideas. Likewise, email potentially allows more coordination through efficiency.

5.6. What possible methods knowledge is required for the use of PPMOF?

5.6.1. (Modularization only) What level of scope is required of a module? Is it tested and operated at the fabrication facility?

McAbee uses P&ID's (piping and instrument diagrams) provided by the engineer to direct the detailed design of PPMOF elements. P&ID's show process flow for the system. McAbee designs the detailed connections, routing, and exact placement. Systems are tested at the fabrication facility according to the contract requirements. The level of testing ranges from hydrostatic testing of components to full-scale erection and testing of entire modular facilities, including foundations. The level of verification required is generally dictated by the on-site schedule

requirements. Projects involving critical shutdowns are examples where full mock-ups have been constructed at McAbee.

- 5.6.2. What considerations for configuration and weight are required to allow use of specific methods for transport, setting, and connection?

Size, weight, and structural design are often dictated by transport requirements. Typical modules are transported by truck in 12' x 12' x 40' sections. Larger modules are possible if access to water and/or railway transport are available at the project site.

- 5.6.3. What operations are required to fabricate, assemble, test, load, and transport units?

McAbee uses the P&ID's from the engineers involved in the project to design the details and routing of components. Once the design is completed and computer modeling to reduce interferences has been completed, modules are assembled in-house. Material layouts and flow considerations have been made in the design of the fabrication areas. The assembly area is separated for piping and vessels fabrication. Raw materials enter one end of the facility and flow through a series of workstations including welding and automated equipment. Overhead cranes and other lifting devices enable the movement of components. Once components are finished in the interior workspace, they are moved outside for assembly verification, if required. Some components are also hydro-tested prior to installation. Once outside, McAbee has the ability and workspace to assemble everything from small modules to complete facilities, depending on customer requirements. After verification and customer acceptance, modules are broken down into shippable components. These pieces can be transported via truck, rail, or barge. McAbee also owns a fleet of cranes capable of handling the modules and erecting them onsite.

- 5.6.4. Are there required fabrication tolerances to allow efficient field connection?

Tolerances are generally within 1/8".

- 5.6.5. (Modularization only) What are the preferred sequences for module setting, connection, and start-up?

Sequencing depends on site conditions and can be tested through either 3D modeling or assembly verification.

- 5.6.6. What changes in design requirements related to operational safety and maintenance are considered?

O&M is considered throughout the process of design and is specifically addressed through the use of 3D models and during design review meeting. Some 3D objects have specific parameters of clear spacing that are incorporated into the interference checking.

6. Contracts/Project Delivery

- 6.1. What types of contracts are typically used?

Many of the projects are time and materials with a fixed price.

- 6.2. How is payment made?

Contractual terms and conditions are generally agreed upon prior to commencement of a project. Progressive payments, based on milestones, are preferred but several methods of reimbursement are available.

6.3. How does the project delivery method affect supplier/fabricator involvement?

While traditional design-bid-build works for PPMOF, design/build concepts seem to better facilitate the use.

BE&K, INC.

Overview

BE&K is a construction and engineering company involved in mostly industrial projects. They provide a broad range of engineering and construction services, from conceptual engineering to start-up and as built documentation. Projects range from pulp and paper to chemical processing to manufacturing facilities. While many projects could be classified as heavy industrial, the company also does work on entertainment and pharmaceutical capital projects. The company trains and maintains an open shop field labor force of approximately 8500 workers. The company also participates in maintenance activities. Work is done throughout the US and in a number of overseas locations. BE&K has some experience with PPMOF techniques, with most of the activity in the pre-assembly and prefabrication.

1. Profile

- 1.1. Company/Project name BE&K
- 1.2. Type of industry Light and Heavy Industrial
- 1.3. Type of work Pulp and paper, chemical/petroleum process, manufacturing
- 1.4. Location Birmingham, Alabama
- 1.5. How is PPMOF used the company/on the project?

Prefabricated/Pre-assembled

- Concrete buildings (walls, columns, beams, roof)
- Structural Steel
- Pipe Bridges
- Stairs
- Pipe spools, piping, pipe racks
- Mechanical (conveyors, elevator lifts, tanks, stacks, winders)
- Insulation
- Overhead cranes

Modular

- Chemical process facilities
- Petroleum

2. General Questions regarding PPMOF

2.1. What are the drivers?

- Safety
- Schedule compression
- Parallel work
- Outage schedule/ downtime requirements
- Workforce shortages
- Site conditions
- Cost reduction
- Contract incentives

- Time to market
- 2.2. What are the project objectives and how do they influence the use of PPMOF?
 - Safety risk reduction – promoted by ground level work of PPMOF
 - Outage reduction – PPMOF can potential reduce install and rework time
 - Cost/Schedule reduction – potential with PPMOF techniques
 - Time to market – parallel PPMOF activities can facilitate
- 2.3. What are the benefits?
 - Increased safety
 - Less installation time required
 - Less downtime, outage time
 - Helpful during labor shortage
 - Decreased big crane usage
 - Less onsite work
 - Parallel activities
 - Compress schedule (civil work while pre-assembling)
 - Improve critical path
 - Worker retention (workers prefer ground level work, improved conditions)
 - Decreased shipping and travel costs
 - Decreased printing costs
- 2.4. What are the impediments?
 - Increased space requirements for pre-assembly
 - Increased engineering
 - Increased crane requirements
 - Increased preplanning
 - Procurement can be a problem if handled by inexperience or stingy owner
 - Size limitations (some items are simply too big to modularize)

3. Recent Developments

3.1. Technology - Compared to 15 years ago, how have the following affected the use of PPMOF?

3.1.1. Equipment

For construction equipment, improvements in crane size and technology are helping to facilitate the increased use of PPMOF concepts. For equipment that is part of a facility to be built, PPMOF concepts have been claimed to reduce outages. PPMOF equipment could potentially be installed faster due to pre-testing and completeness of the assembly. Pre-assembled permanent equipment brought in early in the project can also help with other tasks. For example, pre-assembled paper machines can be brought in using a facility's overhead cranes, installed early in the construction process.

3.1.2. Design (3D CAD, 4D CAD, etc.)

3.1.2.1. Visualization

3D CAD provides potential for visualization improvement, specifically for pipe and mechanical drawings. 3D CAD has been used to

model pipe down to 1" in diameter. Pipe isometric drawings are also used for visualization. Structural design and connections are still done mostly in 2D, since software has not been able to address certain issues regarding structures in 3D. 3D visualization has been used to communicate ideas and concepts to the owner, as well as in design for operations and maintenance.

3.1.2.2. Interference checking/field fitting reduction

3D CAD is used for checking interferences.

3.1.2.3. Other Technologies

As Built Technology, Inc., a BE&K owned company, uses photogrammetry and laser scanning techniques to produce as built information. As Built Technology claims accuracies to the sub-millimeter level are obtainable. These measuring capabilities could be useful for design of PPMOF tolerances, connections, and sequencing.

3.1.3. Information technology (Internet, intranet, EDI, bar coding, etc.)

3.1.3.1. Coordination

3.1.3.1.1. Lead times

While IT generally decreases lead times, specific examples were not identified.

3.1.3.1.2. Access to drawings/information

Access to drawings has potential for improvement through direct connection between the contractor, engineers and owners. These connections are capable of improving transmission of information as well as documentation. BE&K has not gone completely electronic, as they still require hard copies for legal reasons. Besides legal issues, another consideration is printing. With the increased use of electronic files, identifying who on a project is responsible for the limited printing that is done is necessary. This should be handled in the contract.

3.1.3.2. Organization

3.1.3.2.1. Participant communication

BE&K claims that information technologies have further enabled international communication. For example, a current project for a major Japanese car manufacturer involves coordination of project participants in Alabama, California, Canada, and Japan. The use of the internet to transmit drawings and email to communicate ideas involves many players, regardless of location.

3.1.3.2.2. Levels of involvement

During the design stage, integration of drawing creation and revision takes place between the owner, engineers, and general contractor. Subcontractors and vendors do not have access to the drawings until the design drawings are ready.

3.1.3.2.3. Integration of multiple sites

Engineers in multiple locations edit drawings and updates are automatically made nightly. Drawings are not official until a

hard copy with the stamp is produced, reducing confusion between drawing versions passed through the internet.

3.2. Economics

3.2.1. How has the economy and labor situation played a role in the decision to use PPMOF?

BE&K feels that labor considerations are important in considering the utilization of offsite work. Areas with strong union influences can factor against. Past experience of project managers has shown that negotiations with local officials may be necessary to reduce project interference. In some cases, projects have been negotiated to have half union, half open shop.

Other labor considerations for the use of PPMOF include the lack of skilled workers and the tendency of workers to prefer the safety benefits of PPMOF work. Some workers may refuse to work at 100' to install a pipe even with adequate safety equipment, so therefore the ground level work associated with PPMOF has been cited as more attractive and useful for worker retention.

4. **Future of PPMOF**

4.1. What areas of new applications of PPMOF have the highest potential?

BE&K would like to expand its use of PPMOF. Proven pilot projects and the increased availability of service from vendors could potentially help with expansion. Some specific new applications would be in equipment and control systems such as airlocks and control rooms. Further expansion would include increased use of prefabricated concrete structures for plants and other enclosures. Modular construction may have increased uses for the chemical and petroleum process facilities and push the size limits for transportation. Future information technologies applications may help facilitate improved communication necessary for PPMOF, including the use of two-way cellular phones on the worksite, increased use of 3D modeling of structural components, third party data basing and increased use of video conference calling to reduce travel costs. Project sites may also be connected by satellite link in the future. Reduced cost of technology, along with quicker installation times and the elimination of hard wire installation to the site make this option attractive for future applications. One new technology idea that was not as well received was the concept of electronic or "e" signatures. Many firms still prefer the hard copy official version for legal reasons.

4.2. What are the barriers to the implementation of these new applications?

Many of the potential barriers identified by BE&K are cultural in nature. Many project players, including engineers, project managers, vendors, and craftsmen are still unfamiliar both with PPMOF concepts and the information technologies that help facilitate them. For the PPMOF culture to be established, several steps are suggested. Engineers may need to alter design thought processes to exploit opportunities and understand limitations of design for PPMOF. For example, PPMOF projects may require more detail drawings showing attachment points. Structural design may be dictated by transport and lifting requirements. For vendors, clear scope definitions of prefabrication versus pre-assembled must be

clarified in some cases. Communication of new concepts to craft workers through training may increase awareness on the construction site. For IT considerations, management's attitude towards technology acceptance may influence the extent to which benefits are realized.

5. Decision Making

5.1. How is the engineer/contractor typically involved in the decision to use PPMOF?

Often times BE&K will make the decision to use PPMOF, since they are usually responsible for determining construction methods on the project. On other occasions the decision is owner driven and part of contractual requirements for safety reasons.

5.2. What factors considered in analyzing possible use of PPMOF?

Safety, cost, schedule and outage impact are identified as major factors.

5.3. What are the key criteria used to make the decision?

Key criteria depend on the project objectives and factors. For example, key criteria for a facility maintenance project may include the minimization of outage duration. Another example involves safety considerations. Some owners require more extensive considerations beyond federal safety requirements. If a PPMOF technique helps to minimize an outage or decrease potential safety risks, then it may be considered for the project.

5.4. How is preplanning involved in the decision making process?

Since the decision to use PPMOF concepts is typically early in the project, it can be considered during the preplanning process. PPMOF generally increases the amount of preplanning required for a project.

5.5. Who makes the decision to use PPMOF?

BE&K generally makes the decision to use PPMOF on their projects. Since they often handle projects on an EPC basis, coordination between engineers and contractors is all in-house and benefits of PPMOF can be maximized. In some cases, the owner has required the use of PPMOF for safety reasons.

5.6. How is the decision made?

5.6.1. At what stages in a project are decisions made most successfully?

Decisions have been made both prior to bidding and after job acceptance. Overall, the decision to use PPMOF should be made as early as possible.

5.6.2. How does PPMOF affect preplanning?

PPMOF increases preplanning. Scope definition should be well defined.

5.6.3. Are there flexibility issues?

Flexibility can be a concern and changes during the project can increase costs. Specific examples were not identified.

5.6.4. How do you determine the level of PPMOF?

The level of PPMOF depends on the project objectives. A requirement such as minimization of outage duration could potentially increase the level of PPMOF.

6. Information requirements and flow using PPMOF

6.1. How have new technologies affected the flow of information between the key players? (Such as internet, intranet, EDI)

New technologies have been claimed to improve information flow on projects, allowing easier and more efficient access and global coordination.

6.2. What level of information exchange is required for a PPMOF project?

Information requirements vary throughout the project. Information such as P&IDs and plot plans are generally required to be made available to the contractor during construction.

6.3. Are there security issues?

BE&K claims to maintain electronic security in several ways. Information and drawings are transferred through secure sites with encryption. Firewalls reduce the potential of unauthorized access or tampering.

6.4. Are there standards for information exchange?

Exchange of different file formats and conversion issues are still a concern. One example is in the use of CAD software. Engineers tend to prefer to use Intergraph software such as MicroStation, but because clients tend to operate in AutoCAD, BE&K has decided to use AutoCAD. It is believed that standards for file formatting are possible, but this concept will probably need to be addressed and driven by the software companies.

6.5. Coordination needs

6.5.1. How is coordination handled in general between the owner, contractor, designer, fabricator, and/or supplier?

Coordination is handled through team meetings, conference calls, emails, or postings on a project-specific website. Meetings can be held in person, via phone conferencing, or video conferencing. BE&K claims improvements in technology have helped to reduce travel to meetings.

6.5.2. How is structural design handled for loading and human access considerations during different phases of the project?

Considerations are given for operations and maintenance during the design process. 3D models have been used to assist in the design of space requirements for such activities.

6.5.3. What requirements are there for tracking the configuration, weight and center of gravity for each component?

Considerations with regards to configuration, weight and center of gravity are made for layout design, lifting and placement considerations. Modules and prefabricated components tend to have more structural steel than their conventional counterparts. One consideration is the integration of columns within the structure. For example, four intersecting corners of four modules could make up one column. This can affect layout and capacity calculations. Attributes for elements are tracked for lifting considerations. Lift points are selected and connections designed for placement and efficient completion. On one process plant project, the owner wanted 85% pre-assembly to increase safety during construction.

6.5.4. What are the requirements for materials management activities through the life of the project? (From initial definition of requirements through

procurement, supplier technical information, expediting, fabrication, factory testing, and delivery)

Materials are managed and tracked by their purchase order number. Some materials are color coded according to their location on the project site. Material management tools such as bar codes and RFID technologies have not been demonstrated as technically or financially feasible to the level expected by BE&K representatives. Reasons cited include the fact that passive technologies such as bar codes and passive RFIDs are difficult to adhere to certain elements and reading can be a problem. In addition, locating the tag can be a challenge later on and scanning from far away is difficult. More expensive active RFID tags have been developed to alleviate these problems but the cost has been deemed too high.

6.5.5. What considerations for configuration and weight are required to allow use of specific methods for transport, setting, and connection?

Component configuration and weight were designed for lifting and placement. Elements were structurally designed to withstand bending forces under their own weight during lifting. Connections were designed to allow quick yet accurate placement. This was accomplished by configuring the connections with a gradually increasing pin and slot design.

Size and configuration were also considered when planning a laydown area for pre-assembly or temporary storage of prefabricated or modular components. Typically, 50% more space is required for these activities.

6.6. What operations are required to fabricate, assemble, test, load, and transport units?

Specific modular cases were not cited. In the case of prefabricated concrete structural components, off site production was used. Elements were cast in a facility in Atlanta and then shipped by truck to the construction site. The supplier checks tolerances and connections prior to shipping. For pre-assembled components, adequate laydown space must be plan. Delivery and assembly schedules are coordinated with onsite work.

6.7. Are there required fabrication tolerances to allow efficient field connection?

Tolerances are generally checked prior to assembly or connection to insure field connections. Tolerances of 1/8" are not uncommon. Some prefabricated pieces may have 3-5" of field trim available to be cut on site to exact length during pre-assembly. About 80% of components are designed for exact fit with no trimming required.

6.8. What are the preferred sequences for module setting, connection, and start-up?

In some cases, the contractor can take advantage of PPMOF concepts by sequencing activities. For example, the construction of a paper mill began with the installation of the large prefabricated building. A subcontractor installed prefabricated columns, beams, walls, and roofing. Working from one end of the large structure, several bays were completed and dry in was established. The permanent overhead cranes were then placed on the completed bays. The cranes could be used to install the pre-assembled equipment while construction of the enclosure continued two bays ahead. This sequencing allowed the contractor to maximize parallel activities and schedule compression.

6.9. Other considerations for information requirements

BE&K extensively tracks a variety of metrics on projects down to the individual craft level. Information on schedule, cost, safety, and productivity are tracked through a database. Some of the information is shared on various levels, even down to the craft worker if the superintendent feels it is advantageous.

7.0 Contracts/Project Delivery

7.1 What project delivery method is typically used? (Turnkey, DB/EPC, EPCM, DBOO, DBB, Maintenance)

BE&K prefers the complete EPC contract, so the company can better control the outcome of a project. They have also been involved in half ownership of facilities built. For example, BE&K was half owner in a paper mill project. This ownership influenced the decision to use PPMOF, since the benefits of cost and schedule savings could directly influence profits and time to market.

8.0 Safety/Legal Issues

8.1 How does the use of PPMOF affect safety?

BE&K claims that the use of PPMOF increases safety. A case could be made for decreased insurance costs and worker's compensation rates, but examples were not available.

8.2 Local and site permitting (impacts on time and cost)?

Construction of prefabricated or modular components could be handled during the permitting process since work is done offsite. In the case of pulp and paper projects, prefabrication of concrete structural components could be completed while site permits were obtained.

8.3 Proprietary information retention?

Secrecy agreements are used to protect proprietary information.

8.4 Environmental restrictions?

Environmental restrictions have not played a part in the use of PPMOF. However, new environmental laws and outage restrictions may facilitate the use of PPMOF. For example, new environmental laws may require upgrades on a pulp and paper facility. Since upgrades may interfere with production activity, PPMOF methods may provide schedule compression advantages to reduce outage time.

8.5 How is insurance impacted?

There is a potential for cost savings due to reduction in insurance cost resulting from the use of PPMOF concepts. Increased safety due to factors such as factory conditions, ground level work, and decreased site exposure could potentially be used to make a case for lower premiums.

JACOBS APPLIED TECHNOLOGY, INC.

Overview

Jacobs Applied Technology (JAT) designs and constructs process facilities for industrial construction projects. Projects vary from greenfields to rebuilds to expansion, and are executed throughout the world. The Charleston facility is primarily involved in the design and fabrication of modular units for process facilities. With the engineering and fabrication on one site, JAT believes efficiency and coordination are increased. Clients vary from partnerships to competitive bid contracts. The 94-acre facility consists of engineering offices, several large fabrication buildings and access to major roads, rail, and waterways.

Engineering facilities include multiple computer stations loaded with computer design PDS software and are linked to other Jacobs offices via an intranet. Fabrication takes place in large buildings designed to accommodate large assemblies. Raw materials for construction are ordered by project and delivered in a just in time manner to reduce bulk inventory. Structural steel begins in a fabrication shop where large jigs are used to assemble structural frames for modules or preassemblies. Overhead cranes, forklifts and rollers are used throughout the facility to move components. Components are then moved into a paint shop or are sent to galvanizers as required. Once finishes are completed, components are moved into another building for further assembly and equipment installation. Components such as vessels, piping, control boxes, and electrical conduits are then installed on the modules. Dedicated personnel check components to maintain specific tolerances for quality control. Temporary structural supports are placed as dictated by shipping, lifting, or assembly considerations. Completed modules are then protectively wrapped and placed on truck, rail, rail or barge. Individual pieces of structural steel or other components required for stick assembly are also loaded, usually on a separate vehicle.

1. Profile

- 1.1. Company/Project name Jacobs Applied Technology (JAT)
- 1.2. Type of industry Industrial process
- 1.3. Type of work Process, chemical, petroleum facilities
- 1.4. Location Charleston, SC
- 1.5. Contact information/People interviewed see above
- 1.6. How is PPMOF used the company/on the project?

JAT uses modularization, preassembly and prefabrication concepts to build chemical and other industrial process facilities.

Several modular examples were given:

- Chevron Chemical Oak Point expansion
- Arco Products Polypropylene plant
- Rhone Poulenc Wet Acid project
- Conoco pipe racks
- Rhone Poulenc Methomyl Larvin Pesticide

- FMC Dvester project
Pre-assemblies may include piperacks, motor control centers (MCC), stairtowers, and pipe/equipment assemblies.
Prefabricated components include structural elements or “field steel” for use in the installation of modular or preassembled components.

1.7. What percentage of work is PPMOF?

Projects are generally 50% modularized. Some projects can be as much as 75% modular.

2. General Questions regarding PPMOF

2.1. What are the drivers?

Drivers vary from project to project, and often times one or two factors can “bubble up” to drive or impede the use of modularization.

Client business drivers:

- Time to market
- React to market changes
- Financial viability (ROI/EVA)
- Health, safety and environmental
- Technology protection

Project Drivers:

- | | |
|------------------------|--------------------------------|
| • Business Demands | • Safety |
| • Schedule | • Permitting |
| • Cost | • Local Labor Availability |
| • Quality | • Risk Reduction |
| • Site Constraints | • Contaminated Soil |
| • Impact on Operations | • Weather |
| • Design Constraints | • Improved Project Performance |

2.2. What are the project objectives and how do they influence the use of PPMOF?

- Meeting schedule/start up date/business target (Modular helps to meet schedules through risk reduction and parallel construction.)
- Accurate cost control (Modular can improve cost performance through the use of more productive workers, risk reduction, and decreased rework.)

2.3. What are the benefits?

- Increased safety from indoor work
- Schedule compression (FMC Dvester project, Rhone Poulenc Wet Acid Project)
- Cost reduction (FMC Dvester project, Arco polypropylene plant)
- Risk reduction from indoor work
- Lower cost and schedule variances (Rhone Poulenc Methomyl Larvin pesticide, Chevron Oak Point Expansion)
- Parallel activities
 - Maintain start up date even when FEL slips (Chevron Oak Point Expansion)

- Offsite construction while permitting or remediation (Rhone Poulenc, Wet Acid Project)
- Civil or structural work while off site construction (Conoco pipe racks, Rhone Poulenc Methomyl Larvin pesticide)
- Faster time to produce product at start up (Chevron Oak Point Expansion)
- Shorter onsite duration (Arco polypropylene plant)
- Faster erection time (Arco polypropylene plant)
- Smaller footprint (Arco polypropylene plant)
- Schedule Compression (Arco polypropylene plant)
- Increased safety in OSHA restricted areas (Rhone Poulenc, Methomyl Larvin pesticide)
- Higher worker satisfaction
 - Indoor work
 - Low work
 - Competitive wages
 - One work location

2.4. What are the impediments?

- Transportation
 - Truck
 - 16'x14'x60' typical, lengths can potentially reach 120'
 - 70 ton max
 - Size limits exceeded by some equipment
 - More interfaces
 - Rail
 - 14'x14'x100'
 - 100+ tons
 - Unreliable schedule, limited access
 - Barge
 - 96'x320'
 - 2000 tons per module
 - Site must be near water
 - May cost more than land transport in some cases
- Cultural issues
 - Some clients see modules as cramped units.
 - Some misunderstandings about skids vs. modules
 - Engineers need to learn “artform” of modular (design of interfaces, equipment positioning, structural design of supports)
 - Understanding that modular is a method or approach, not a product

3. **Recent Developments**

3.1. Technology - Compared to 15 years ago, how have the following affected the use of PPMOF?

3.1.1. Equipment

For module erection, increased capacities and level of control of hydraulic cranes has helped to set modules. Increased capacities allow

larger module setting in constrained areas with less set up time. Finer control allows modules to be placed in some cases in a single lift, rather than rough placing and jacking into position.

3.1.2. Design (3D CAD, 4D CAD, etc.)

3.1.2.1. Visualization

3D CAD and PDS software has improved visualization on projects. Past methods involved the construction of plastic models that required their own fabrication facilities and staff. Computer models can be used for engineering and constructability reviews. Erectors can use the software to determine lifting considerations. Operations and maintenance personnel can view different areas to determine accessibility and operations. Clients can view the model from any angle. Shop supervisors can access the model in office on the shop floor to check layouts.

Models include steel, pipe, all aspects on the P&ID, lights, cable trays, junction boxes and soft spaces. Interfaces between modules are designed, as well as interfaces with stick built, existing or foundation areas.

The modeling software includes the capability to move equipment and other large items from outside into final position to assist with installation planning.

3.1.2.2. Interference checking/field fitting reduction

Interferences are checked with the 3D model. Software detects conflicts and alerts the user. The user can manipulate components and equipment to determine interferences associated with lifting, placement, or operation. Computer generated isometric drawings reduces possibility of fabrication error or field fitting problems. Quality control by personnel using the model and isos reduces field rework.

3.1.3. Information technology (Internet, intranet, EDI, bar coding, etc.)

3.1.3.1. Coordination

3.1.3.1.1. Access to drawings/information

AT intranet allows offices across the country to communicate ideas and transfer drawings. Some clients also transfer drawings electronically with JAT.

3.1.3.2. Organization

3.1.3.2.1. Integration of multiple sites

Computer can link multiple design and construction offices, as well as client offices. JAT prefers to have its modular design offices on the same site as the fabrication facility. This allows engineers and shop staff to interact directly.

3.2. Economics

3.2.1. How has the economy and labor situation played a role in the decision to use PPMOF?

Craft labor cost, quality and availability has played a role in past projects and driven the use of PPMOF concepts. Off site fabrication of modules was more effective on the Chevron Chemical Oak Point expansion

and the Rhone Poulenc Wet Acid project due to the limited availability of labor. Labor rate differentials on the Arco Products polypropylene plant drove modular construction. Some sites were restricted in the amount of craft labor allowed at the site due to operations or site size constraints. These include the Conoco Pipe Racks and the Chevron Chemical Oak Point expansion.

4. Future of PPMOF

4.1. What areas of new applications of PPMOF have the highest potential?

The future of PPMOF has the potential to include increased integration and standardization of project processes. Many operations currently handled manually could be automated in the future. For example, smart P&ID's could be used to download component and process data directly into the PDS model. Future models may include structural connections, electrically conduit and full cable tray modeling.

4.2. What are the barriers to the implementation of these new applications?

Barriers are both technological and cultural in nature. Advancements in computer technology will eventually allowed increased integration of project information, from smart P&ID's to database and 3D model integration to automatic generation of materials lists, estimates, and procurement. Cultural barriers include lack of industry knowledge regarding the potential benefits from PPMOF concepts. JAT feels that some preconceptions about the concepts are outdated and improperly biased. In some cases, clients could not benefit completely from the methods due to lack of understanding or ability to recognize conditions best suited for PPMOF.

5. Decision Making

5.1. How is the engineer/contractor typically involved in the decision to use PPMOF?

JAT works with the client to determine the applicability and level of PPMOF to be used on the project. JAT has developed general considerations for decision making. The general questionnaire is primarily for clients to use as a checklist for projects to determine the applicability of modularization to their project.

5.2. What factors considered in analyzing possible use of PPMOF?

- | | |
|-------------------------------|----------------------------------|
| • Schedule issues | • Site conditions |
| • Level of ROI | • Labor availability and quality |
| • Safety concerns | • Impact on operations |
| • Site access/ Transportation | • Facility density |
| • Site Constraints | • Equipment size |
| • Quality requirements | • Productivity Issues |
| • Financial considerations | • Project and business risk |

5.3. What are the key criteria used to make the decision?

While types of criteria are applicable to many projects, weights vary from project to project. One factor may override other factors. JAT is in the process of developing a decision matrix tool with criteria for determining modularization

potential. The criteria and weighting was based on team member experience with PPMOF concepts on projects.

Project criteria include:

- Stage of development
 1. Detailed design
 2. Prelim design
 3. FEL or conceptual
 4. Feasibility
- Nature of process
 1. Bulk solids, low density
 2. Some solid, high density
 3. Gas or liquid, low density
 4. Gas or liquid, high density
- Safety concerns
 1. No hazards
 2. Moderate hazards
 3. Significant hazards
- Craft availability
 1. Plentiful craft and skill
 2. Tight craft, enough skill
 3. Limited craft, skill
- Productivity
 1. No obstacles
 2. Potential obstacles
 3. Significant obstacles
- Replication
 1. None
 2. Maybe
 3. Highly probable
- Transport options
 1. Truck only
 2. Truck and/or rail
 3. Truck, barge, rail
- Equipment size
 1. Large, over 20'
 2. 10'-20'
 3. <10'
- Schedule compression
 1. No advantages
 2. Possible advantages
 3. Significant advantages
- Labor cost
 1. << Gulf coast
 2. < Gulf coast
 3. = Gulf coast
 4. > Gulf coast
 5. >> Gulf coast
- Existing operations
 1. Not essential
 2. Somewhat essential
 3. Critical

5.4. How is preplanning involved in the decision making process?

The decision to use modularization is generally part of the preplanning process once conceptual design and general process decisions have been made.

5.5. Who makes the decision to use PPMOF?

The project team consisting of JAT, the client, and other players make the decision.

5.6. How is the decision made?

5.6.1. At what stages in a project are decisions made most successfully?

The decision to use modularization is best made early in the project, before detailed design or estimation. Typically the decision is made during basic engineering or earlier. This requires the owner to commit prior to detailed estimation in order to gain the full benefits of modularization.

5.6.2. Are there flexibility issues?

Flexibility decreases as the level of engineering detailed design increases. The project team reviews models with the client, as well as operations, maintenance, shop fabricator representatives, and field constructors. All input and requested changes are documented and the model layout is finalized for detailed design. The design is then “frozen” with all considerations taken into account and documented. As detailed design is completed and fabrication of modules has begun, then changes to design become increasingly higher in cost.

5.6.3. How do you determine the level of PPMOF?

The level of PPMOF use is determined through a screening process developed by JAT. The process evaluates project drivers, site conditions, transportation options and available methods to determine the level of PPMOF to be implemented. The team first identifies if part of a project can be constructed using PPMOF methods. Then an analysis is made to determine if such methods are feasible given project attributes. This process helps to identify which parts of the project should use PPMOF methods and which should be stick built.

Recent projects have influenced the level of PPMOF JAT considers. Components that were traditionally stick built, such as structural frames connecting modules, may benefit from PPMOF methods. These frames, essentially empty steel skeletons, would have potentially been assembled and shipped more cost effectively than stick built on site, even though they did not contain equipment. The cost of transporting empty space was estimated to be less than the cost of decreased field productivity.

5.6.4. Does your company have a specific decision making process for the use of PPMOF?

JAT uses a specific screening process to determine the use of PPMOF concepts. Factors included in the screening process include:

- Schedule issues
 - Business requirements
 - Site constraints – weather, site availability
 - Permitting
 - Equipment deliveries
 - Required labor density
 - Series Construction constraint
- Quality requirements
 - Degree of NDE
 - Material requirements
- Productivity Issues
 - Shop vs. field
 - Weather
 - In-Plant environmental issues
 - Height adders
 - Site logistics
 - Site work rules
- Site safety issues

- Financial issues
 - Capital cost
 - Revenue associated with early productions
- Business risk
 - Cost creep
 - Schedule slippage
- Project execution issues
 - Process changes
 - Future expansion
- Business requirements drive decision

6 Information requirements and flow using PPMOF

6.1 How have new technologies affected the flow of information between the key players? (Such as internet, intranet, EDI)

Jacobs's offices are connected via a company intranet. Offices can transfer files and communicate by email. To the interviewee's knowledge, the company has not become involved in project specific websites over the internet. Some project information is transferred to the client electronically to communicate design ideas and concerns.

6.2 Coordination needs

6.2.1 How is coordination handled in general between the owner, contractor, designer, fabricator, and/or supplier?

The shipping book and the erection package are examples of coordination between the fabricator and the erector. These documents contain information concerning work items remaining to complete the modules along with detailed instructions for erection.

6.2.2 How is structural design handled for loading and human access considerations during different phases of the project? (Fabrication, transport, rigging, connection, testing, operation, maintenance)

Considerations for loading and human access are completed during the computer model design. Three model review meetings and two constructability reviews are conducted to check for such considerations. Components can be assigned envelope values for space considerations. For example, a loading door may require space for opening or a valve requires space for personnel to operate. The model calculates the space required for these considerations and alerts the designer to potential conflicts. Design envelopes can be placed around entire modules to maintain size restrictions dictated by shipping or lifting constraints. Each module is structurally designed as a separate design file and then assimilated into the entire model. JAT claims this allows easier construction phasing and shorter schedules.

6.2.3 What requirements are there for tracking the configuration, weight and center of gravity for each component?

Key tracking requirements include module weight, interface points between modules, and classified areas such as rooms with increased fire rating. Ability to track these types of information is essential for design coordination as well as for selecting different shipping units.

- 6.2.4 (Modularization only) How are process system and utility system (e.g., cooling water, compressed air, drain, electric power) coordinated for independent testing and operation of modules? (Coordinating these systems requires tracking loads, system completeness within assemblies, and interfaces between assemblies)

Independent testing is generally not required. The systems are designed for the entire plant and then separated into modules. Electrical systems are designed for independent wiring with modules, with the exception of motor feeders. Splices are not allowed in these cables so they are designed for complete pulling at the site.

- 6.2.5 What are the requirements for materials management activities through the life of the project? (From initial definition of requirements through procurement, supplier technical information, expediting, fabrication, factory testing, and delivery)

Each component in the PDS model has attributes associated with it and can be pulled up from a database by simply clicking on the component. Vendor specifications and any other attributes can be assigned to the component as defined by the user. Components are separated and tagged by module.

Temporary support components are indicated by red paint to decrease confusion during assembly.

- 6.3 What possible methods knowledge is required for the use of PPMOF?

- 6.3.1 What considerations for configuration and weight are required to allow use of specific methods for transport, setting, and connection?

Transportation considerations depend on the method of transportation. Modules can be shipped via truck, rail or barge. Considerations must also be made depending on site location. State laws west of the Mississippi river tend to be more favorable to module transportation. Access to major roads, rail lines or waterways will also factor into transportation considerations.

Method	Size Limit	Weight Limit
Truck	16'x14'x120'	70 tons
Rail	14'x14'x100'	100+ tons
Barge	96'x320'	2000 tons per module

Special considerations must also be made since modules are built horizontally but operate vertically. Considerations are made for setting by analyzing loads in different conditions, such as lying horizontal on a module's side to the upright and final position. Overall weight, lifting points, and center of gravity are considered. Critical lifts are designated over a certain weight. Field personnel are responsible for the lift planning. Planning can be accomplished through the use of the PDS models, which help to identify restrictions and interferences.

Setting and connection to the foundation is modeled using PDS the same as an interface between modules. Connections are bolted and grouted to the foundation. Connection between modules is calculated through the

PDS and quality controlled dimensions are built to 1/8" tolerances, minimizing field connection problems.

6.3.2 What operations are required to fabricate, assemble, test, load, and transport units?

Fabrication begins with the construction of structural elements from raw steel materials delivered from providers. Structural frames are fabricated in special jibs to insure proper alignment. Once structural assemblies are completed, units are moved into a paint shop where they are sandblasted and painted. Some components are shipped back to the steel supplier for galvanization.

After painting, units move into another bay for further assembly and installation of equipment. Here vessels, piping, pumps and other equipment are installed. Temporary bracing and structural steel is installed to assist in the fabrication or to strengthen for shipping. Shop personnel have access to the computer model via in-shop terminals or computer printouts.

Some components are then tested according to client requirements. For example, some piping is hydrotested. Assemblies consisting of a small number of modules can be fully connected and assembled, if required by the client.

6.3.3 Are there required fabrication tolerances to allow efficient field connection?

1/8" tolerances are the general specification.

6.3.4 (Modularization only) What are the preferred sequences for module setting, connection, and start-up?

Field personnel review models to determine installation sequences. Sequences are done manually and generally are done from large to small and inside to outside for module setting.

6.3.5 What changes in design requirements related to operational safety and maintenance are considered?

Changes made to designs with regards to operational safety and maintenance are identified in the 3D model reviews. Changes are documented for later verification.

6.4 What are the possible component information and attributes required?

6.4.1 (Modularization only) What are some examples of possible component systems? (Systems and members; process equipment such as pumps, compressors, heat exchangers; piping systems and components; electrical systems including equipment, raceway, and cables, and control systems)

- Piping (steel, stainless steel, glass lined, plastic with metal lining, fiberglass and others)
- Heaters
- Heat exchangers
- Vessels
- Gravity feed systems
- Pumps and compressors
- Electrical systems (conduit, trays, junction boxes, controls)
- Motors

- Walkways, railings, stairs
 - Lighting
 - Safety equipment (eye washes, fire control)
- 6.4.2 What are the technical attributes of components? (Function and capacity, design criteria and calculations, weight, size, center of gravity, utilities and services required, access to install and maintain, technical data from supplier describing operation and maintenance)

Technical attributes are tracked within the PDS model as part of a database. These include:

- Size (length, diameter, etc)
 - Weight
 - Ratings
 - Center of gravity
 - Vendor info
 - Human access requirements
- 6.4.3 How is quality control handled for components? (Documentation from design, fabrication, installation, and testing; materials certification; quality problems and their resolution)

Specific JAT personnel are responsible for quality control on a project. They check measurements and verify with the computer models.

7 Contracts/Project Delivery

7.1 What types of contracts are typically used?

JAT has used both negotiated and competitively bid lump sum contracts. In some cases, the project begins as cost reimbursable until detailed design firms up the estimate, at which time the contract moves to a negotiated lump sum. This is mainly due to the requirement that the client commits early to use modularization, even before a fixed estimate can be made.

7.2 What project delivery method is typically used? (Turnkey, DB/EPC, EPCM, DBOO, DBB, Maintenance)

JAT prefers to handle projects on an EPC or EPCM basis. By handling both engineering and construction JAT believes they can provide the highest level of service to its customers.

8 Safety/Legal Issues

8.1 How does the use of PPMOF affect safety?

Jacobs claims that safety levels are more of a company issue rather than a result of modular versus stick. While ground level work does reduce risk, safety is more dependant on company attitude and worker training.

8.2 Local and site permitting (impacts on time and cost)?

For projects in which permitting has been a delaying factor, modular construction has helped by moving work offsite. Permits can be obtained during shop fabrication. One example is the Rhone Poulenc Wet Acid project in which the permits were late but modular construction continued, resulting in full production capacity four months ahead of the business target.

8.3 Proprietary information retention?

Technology and proprietary information can be protected by modular design. For example, an Amerchol project in China was built modular to protect technology in the facility. The modules could be built in the US and then packaged for China. Critical aspects exposed during construction could be built offsite to retain information.

8.4 Environmental restrictions?

Projects involving adverse site conditions, such as contaminated soil, have benefited from modular construction. At the Rhone Poulenc Wet Acid project, contaminated soil was found and remediation was executed during offsite fabrication.

PROQUIP CORPORATION

Overview

Pro-Quip is a turnkey provider of process plants and subsidiary of the German industrial company, Linde AG. Pro-Quip specializes in modular construction. The Tulsa facility is located on an inland waterway and fabrication shop space of approximately 165,000 sf is available. 99% of their jobs are lump-sum turnkey projects and they do about \$100 million/year. While Pro-Quip operates on a relatively low-tech basis compared to other modular fabricators, their attention to organization and full engineering and construction capabilities seem to be the key to their success.

Pro-Quip believes the concept of modularization and fast track scheduling are not mutually exclusive. They try to reuse designs when possible and have developed a stock plant design.

They appear to be moving toward full implementation of 3D CAD capabilities in the near future. Much institutional knowledge is required of designers for good modular design, so turnover must be minimized. Training such experienced engineers may impose significant start-up costs to conversion to 3D CAD and may be an impediment.

Modular vs. Stick Example

An example project was suggested with a total installed cost of \$25M. The job was estimated to take 150,000 field craft hours to complete the job conventionally. All-in labor rates were assumed at \$50/hr at 1.2 times less productive than gulf coast productivity rates. Assuming a third of the labor hours, or 50,000 hours, are transferred to the shop (at \$35/hr and 0.9 gulf coast productivity), then shop craft hours would be about 37,500 hours. The gross savings due to the increased productivity and wage rates was estimated to be \$1.188M or a 16% savings on labor cost. This results in a 5% savings in TIC. Pro-Quip claims the additional costs of freight, additional structural steel and increased coordination requirements will be offset by savings due to schedule reduction.

1. Profile

- 1.1. Company/Project name: Pro-Quip
- 1.2. Type of industry: Industrial
- 1.3. Type of work
Refinery, Gas Processing and Chemical/Petrochemical systems
- 1.4. Location
Tulsa, Oklahoma
- 1.5. How is PPMOF used the company/on the project?

Pro-Quip uses modularization as one of its methods of constructing projects. Modular project examples include gas, hydrogen and sulfur plants; refineries, and continuous catalyst recycle (CCR) platformers. Preassembly and prefabrication are also used to enhance modular projects. Some smaller prefabrication or preassembly projects are handled in order to maintain a certain level of work in the shop. While margins tend to be lower on prefabricated and

preassembled work, Pro-Quip claims they can still compete with “mom and pop” style fabricators.

2. General Questions regarding PPMOF

2.1. What are the drivers?

- Limited plot space
- Difficult labor conditions and high labor costs at plant site
- Remote site location
- Extreme weather conditions at plant site
- Restricted quality of skilled labor at plant site
- Competition, market share
- Schedule, time to market requirements
- Vertical processes
- High pipe density
- Exotic alloys
- High complexity

2.2. What are the benefits?

- 30-50% higher shop productivity over field craftsmen, resulting in considerable cost savings in total project man-hours. These savings offset and sometimes exceed the difference in greater modular engineering costs.
- Permanent skilled craftsman labor pool versus labor shortages in skilled field craftsmen.
- Less field labor required (estimates 20-40% less field labor hours)
- Managed labor relations result in more stable workforce. Better working conditions and environment than in field.
- Skilled labor availability at shop is higher resulting in shorter schedule and increased savings.
- Reduced craft densities and peak
- Reduced field work duration
- Enhanced safety due to ground level work, shop conditions and less field exposure
- Weather related delays are not a factor
- Pro-Quip claims prefabricated and preassembled components are almost always cheaper than conventional
- Require only modest temporary construction site facilities
- Short site construction time allows for flexible installation schedule
- Simplified foundation requirements mean less concrete work labor costs.
- Quality control in fabrication shop results in higher quality plant at lower inspection and testing costs.
- Control of incoming materials and issuing materials simplified by standard procedures. Inventory control is superior due to stable shop situation.
- Shorter overall project schedule (estimates 10-15%)
- Lower overall project cost (estimates 4-8% TIC)

- Permitting advantages
- Schedule flexibility, de-sequencing activities
- Improved risk management
- Less impact on existing operations

2.3. What are the impediments?

- Cultural - industry misconceptions about modular
 - Cramped
 - Hard to maintain
 - Sacrifice space
 - Shipping expense high
 - Fit up problems
- Desire to keep field labor busy (E&C companies)
- Early commitments
- Equipment lead times (main schedule constraint)
- Transportation limitations based on delivery method

3. **Recent Developments**

3.1. Technology - Compared to 15 years ago, how have the following affected the use of PPMOF?

3.1.1. Equipment

Pro-Quip believes the plant equipment technology has not changed much in the last 10 years.

3.1.2. Design (3D CAD, 4D CAD, etc.)

Pro-Quip does not use 3D CAD as a general practice because it has not been demonstrated as economical for their use. However, a sister company does use 3D CAD and pro-Quip is considering a change in policy. Business development and change management are driving its use more in the future. Designers believe that the software may require another generation before full advantage could be taken. Such requirements would include increased integration of component information and vendor specifications, increased file sharing capabilities, and more user-friendly environments within the software. Currently, engineers use PDS software from Intergraph.

3.1.2.1. Visualization

Rather than 3D walkthroughs for client presentations, Pro-Quip prefers to take clients to previous job sites to demonstrate designs. Pro-Quip recognizes that the use of 3D CAD for visualization may present potential marketing solutions to them. The cost has yet to be justified.

Pro-Quip claims visualization of project status and information has been improved through the use of digital cameras. Cameras in the shop or in the field are used to record information and relay it to others. On one project, weekly updates of project progress were recorded with digital images and emailed to the central office.

3.1.2.2. Interference checking/field fitting reduction

PDS allows interference checking.

3.1.3. Information technology (Internet, intranet, EDI, bar coding, etc.)

3.1.3.1. Coordination

3.1.3.1.1. Lead times

Pro-Quip claims the use of the internet to transfer drawings and communicate by email has improved lead times, but no effort has been made to directly quantify the improvements.

3.1.3.1.2. Access to drawings/information

Pro-Quip claims access to drawings and information has improved through the increased use of IT technologies. While quantification has not been specifically carried out, reduced site visits and decreased lead times on information acquisition are apparent to team members. Pro-Quip also feels that savings associated with reduced shipping and printing of materials has also been a result of increased IT use.

3.1.3.1.3. Other

Pro-Quip believes that IT has helped to better integrate design information.

Pro-Quip states that IT has not increased the amount of their outsourcing or promoted 24 hour engineering.

3.1.3.2. Organization

3.1.3.2.1. Participant communication

Participant communication is believed to have improved due to decreased lead-time between communication and increased documentation.

3.1.3.2.2. Levels of involvement

Levels of involvement have not changed due to information technologies. Pro-Quip believes the same project players are involved. IT merely enhances the communication between them.

3.1.3.2.3. Integration of multiple production/assembly sites

Pro-Quip claims that IT technologies have not resulted in expanded use of multiple production/assembly sites. Projects have always required coordination of multiple locations. IT technologies have improved communication but not altered the distance between or amount of locations.

3.1.3.2.4. Other

Some disadvantages of IT include the creation of more information than is necessary at times. Email can be abused by carbon copying too many individuals.

3.2. Economics

3.2.1. How has the economy and labor situation played a role in the decision to use PPMOF?

Pro-Quip believes the current lack of work for large E&C's has resulted in the decreased use of PPMOF. These large companies need to

keep field labor busy, so the exporting of field hours to the shop is not desirable.

However, the high cost and lower productivity of field labor has prompted more owners to use PPMOF for new projects.

4. Future of PPMOF

4.1. What areas of new applications of PPMOF have the highest potential? (These can include extensions of Section 3 or other applications.)

Pro-Quip would like to see more user-friendly 3D design software, with integration of component information. The development of standards for file formats by the industry would also help. Software vendors are beginning to address these concerns in the next generation of programs.

4.2. What are the barriers to the implementation of these new applications?

Cultural barriers as well as the fragmented nature of the industry present barriers to these concepts.

5. Decision Making

5.1. How is the engineer/contractor typically involved in the decision to use PPMOF?

Pro-Quip has an evaluation process for determining stick vs. modular construction. Pro-Quip works with the client to develop a conceptual model based on processes, equipment layout, site conditions, and other factors. From this information, a rough schedule is developed based on conventional construction. The project is then evaluated for modularization potential and recalculated. This evaluation takes place at the management level. Once a decision is made, the evaluation moves to a more detailed analysis.

Further analysis involves the comparison of field and shop labor. An important distinction between the two is the “all in” labor rate. Rates must include the cost of equipment such as cranes and other support in order to make an accurate comparison. Pro-Quip has found that even when the “all in” rates are equal, the shop labor is still less due to the increased productivity resulting from improved shop work conditions, easier access to equipment and tools, and the elimination of weather delay.

5.2. What factors considered in analyzing possible use of PPMOF?

Factors such as business needs, equipment and layout requirements, as well as site and labor conditions are considered. Several steps are considered for determining applicability of a project for modularization:

- Assessment begins with reverse engineering – start with shipping
- Shipping size determines modular design constraints
- Check equipment fit for modular envelope

5.3. What are the key criteria used to make the decision?

Key criteria include economic and business needs, labor rates, labor productivity, risk assessment and project drivers such as schedule and site conditions. Site conditions include proximity to operations, permit requirements, craft density and access, existing operations, and craft availability.

5.4. How is preplanning involved in the decision making process?

The use of modularization demands a greater amount of front end planning, which can potentially reduce conflicts later in the project.

5.5. Who makes the decision to use PPMOF?

The project team makes the decision to use PPMOF and how much.

5.5.1. How does PPMOF affect preplanning?

PPMOF increases the amount of preplanning required. Decisions must be made sooner within the process. However, since overall schedule may be reduced, these decisions may possibly be made later in the overall picture.

5.5.2. Are there flexibility issues?

Due to the shortened design cycle, many aspects of a project must be set early.

5.5.3. How do you determine the level of PPMOF?

The level of PPMOF can be dictated by the size and type of equipment to be included in the facility. For example, equipment sizes exceeding the modular envelope would decrease the potential for modularization.

The level of PPMOF may also be determined by the project delivery method. If Pro-Quip is handling the project on a complete turnkey basis, then the full advantages of modularization can be realized. If they are not responsible for field assembly and construction, the level of modularization may be reduced since Pro-Quip will not realize themselves the savings from decreased field labor.

6. Information requirements and flow using PPMOF

6.1. How have new technologies affected the flow of information between the key players?

Pro-Quip feels that information flow has improved through lead-time reduction and increased documentation.

6.2. Are there standards for information exchange?

Pro-Quip claims that lack of standards is a current problem. Standards are needed for electronic information exchange such as CAD file formats.

6.3. Coordination needs

6.3.1. How is coordination handled in general between the owner, contractor, designer, fabricator, and/or supplier?

With regards to procurement, several advantages were identified if Pro-Quip handles procurement. By handling procurement, Pro-Quip has more control over the schedule of delivery and vendor selection. Coordination is handled via electronic communication. Pro-Quip can obtain pricing and delivery status. They use this to set up just-in-time deliveries.

For example, one supplier of pipe fittings, valves and flanges kits assemblies for modules. As part of the alliance, Pro-Quip has full electronic access to product and shipping information. This close relationship allows JIT delivery as soon as two days.

6.3.2. How is structural design handled for loading and human access considerations during different phases of the project?

Constructability studies are used to analyze these considerations throughout the process. The end user often dictates final operations and maintenance requirements during design and fabrication. The designers handle fabrication and transport requirements. The rigging contractor typically handles rigging requirements.

Fabrication of modules is often completed at ground level, with components laid on their side. Engineers design structural elements for both horizontal and vertical considerations, as well as tilted conditions experienced during lifting. Adequate spacing of bracing and temporary support is handled entirely by the engineers. However, shop personnel do sometimes make minor adjustments in the shop for convenience without compromising design.

6.3.3. What requirements are there for tracking the configuration, weight and center of gravity for each component?

Configuration is handled early in the design process with the layout plan. Weight considerations are made in design. Pro-Quip believes center of gravity is usually not a major concern given the experience of field personnel in rigging and short interval lift planning.

6.3.4. (Modularization only) How are process system and utility system (e.g., cooling water, compressed air, drain, electric power) coordinated for independent testing and operation of modules? (Coordinating these systems requires tracking loads, system completeness within assemblies, and interfaces between assemblies)

When possible or required by the client, modules are connected to test systems. The use of extra pipe flanges and electrical junction boxes allows system testing and interface checking prior to shipping. It may also increase costs. In some cases, interfaces requiring welding are welded for testing and then cut for shipping. In cases where connection is not feasible due to design or environmental restrictions, interfaces are simply lined up to check tolerances.

6.3.5. What are the requirements for materials management activities through the life of the project?

Materials are tracked through a tracking log, which linked to a master shipping list. Raw materials are ordered on a just-in-time basis to reduce inventory. Technical information from the supplier is often provided electronically on a CD.

6.3.6. How is progress monitored during fabrication, assembly, testing, transportation, and startup?

Foreman and supervisors track progress in the shop. They also do week ahead short interval planning. The information is relayed to a scheduler who coordinates with the design office. The scheduler in turn updates the schedule and provides the shop with more work.

6.4. What possible methods knowledge is required for the use of PPMOF?

6.4.1. (Modularization only) What level of scope is required of a module? Is it tested and operated at the fabrication facility?

Module design begins with P&IDs. Next plot plans and modular layouts are considered, as well as the level of modular and stick construction. From there detailed drawings are made.

Testing and operation requirements depend on the job requirements. Testing ranges from pipe hydrotesting and x-ray analysis to full-scale assembly and verification. Pro-Quip has built entire plants in the fabrication yard for testing purposes. Extra flange connections and electrical junction boxes are used to allow connection and reconnection of modules for assembly. Some environmental restrictions may limit the number of flange connections for pipe, so verification simply dictates that the pipes line up without testing the system as a whole.

6.4.2. What considerations for configuration and weight are required to allow use of specific methods for transport, setting, and connection?

Configuration and weight is dictated by transportation and erection capabilities. Pro-Quip has access to major road, rail, and barge transportation. Road access is limited to 14' square and up to 110' in length. Weight is limited to maximums allowed by permits on roadways. Barge access increases the size and weight considerably, and these attributes are typically constrained by the availability of lifting equipment rather than the shipping constraints. Rail transport is seldom used due to unreliable scheduling and unpredictable handling of components during the shipping process. For example, Pro-Quip in the past shipped flat steel plate by rail but found that the material arrived at the shop bent and mishandled.

Pro-Quip claims that for rule of thumb, 80-100 tons is the maximum economical size of a module.

6.4.3. What operations are required to fabricate, assemble, test, load, and transport units?

Once design drawings have been completed by Pro-Quip's engineering office or from an outside designer, the fabrication shop receives the necessary information for fabrication. The shop is set up more like a manufacturing facility than a construction site, with permanent welding stations, leveling devices, and overhead cranes.

Raw material and equipment, typically from a preferred vendor, arrives on a just-in-time basis to the fabrication yard. Raw material enters the shop through one of the large fabrication bay doors. Separate areas are designated for different activities, such as structural, pipe and vessel fabrication. Frames and structural components of modules are built while parallel construction of necessary pipe, vessels, and equipment are carried out in separate bays. A blasting shop and a large paint shop are used to prepare and coat the structural assembly or other items once they are ready. Components such as pipes, welded structural steel and vessels are tested and examined for quality control. All items are then brought into assembly areas via dollies, forklifts or overhead cranes to be joined together to form the modules or preassemblies. Upon completion of assembly and testing, finished pieces are loaded for shipping either on trailers for road transport or delivered to a nearby barge for delivery via the waterway.

6.4.4. Are there required fabrication tolerances to allow efficient field connection?

Field labor has been brought into the shop in one instance for a project during module testing to assist with disassembly for transport. This increases familiarity and accountability of field labor. This helps to expedite the process of assembly of modules in the field.

While exact tolerances were not identified, some considerations for field fitting are made. For example, extra length may be left onto a pipe to allow for field adjustment.

6.4.5. (Modularization only) What are the preferred sequences for module setting, connection, and start-up?

Constructability reviews are conducted to analyze sequencing of module setting. Sequences will depend on site conditions and module layout.

6.4.6. What changes in design requirements related to operational safety and maintenance are considered?

When applicable, representatives from the client provide input during the design and fabrication. To reduce the misconceptions about modules as being “cramped”, Pro-Quip gives tours of previous work to demonstrate O&M considerations.

It is not uncommon for client reps to visit the fabrication shop to oversee work. Pro-Quip claims that offsite fabrication does not reduce client changes.

6.5. What are the possible component information and attributes required?

6.5.1. (Modularization only) What are some examples of possible component systems?

Examples of component systems and equipment include vessels, furnaces, reactors, plate fin heat exchangers, valves, electrical cable and junction boxes, generators, and refrigeration units.

6.5.2. What are the technical attributes of components?

Specific data regarding technical attributes is available in paper format from vendors and other sources and is managed with a conventional manila folder and file cabinet system. Pro-Quip would like to integrate attributes with design drawings and models.

6.5.3. Attributes related to fabrication, assembly, installation, operation, or maintenance: sequence, access and workspace, handling

Specific attributes were not identified. Additional drawings are required to track connections and interfaces between modules. These drawings contain connection attributes.

6.5.4. How is quality control handled for components?

A dedicated staff is assigned to handle quality assurance. Visual inspection and x-ray analysis are used to examine components. Testing and verification are also conducted.

Quality control of components received from vendors is handled electronically. Some vendors provide CD's with test results and certification for delivered items. Also, since Pro-Quip forms alliances with

vendors, the companies have experience working together and are knowledgeable about each other's practices.

7. Contracts/Project Delivery

7.1. What types of contracts are typically used?

Pro-Quip uses a lump sum contract. A very small amount of work (<1%) of the work is performed on a time and materials basis for feasibility and scope definition studies.

7.2. What project delivery method is typically used? (Turnkey, DB/EPC, EPCM, DBOO, DBB, Maintenance)

Pro-Quip delivers turnkey projects.

8. Safety/Legal Issues

8.1. How does the use of PPMOF affect safety?

Safety is increased due to the decreased number of workers at the jobsite.

The controlled environment of the fabrication facility also increases safety.

8.2. Local and site permitting (impacts on time and cost)?

Construction of modules can begin prior to site permit acquisition, further facilitating late decision, early delivery.

FLUOR DANIEL

Overview

This report is the result of a two-hour meeting and covers mostly decision-making process/implementation, as well as the impact of IT on PPMOF. Fluor Daniel is involved in the use of prefabrication, preassembly and modularization on industrial projects. The company has experience in the traditional offshore and hazardous environment arenas and has transferred knowledge gained to a broader range of projects. These include petroleum facilities, chemical processing, and power generation. The company has a detailed decision and implementation process for the use of PPMOF. Fluor Daniel also extensively uses electronic communication, 3D CAD, and bar coding, which it believes has increased the marketability of PPMOF and the efficiency of its use in construction.

1. Profile

- 1.1. Company/Project name Fluor Daniel
- 1.2. Type of industry Industrial
- 1.3. Type of work Petroleum, chemical, power
- 1.4. Location Sugar Land, Texas
- 1.5. Contact information/People interviewed see above
- 1.6. How is PPMOF used the company/on the project?

Fluor Daniel uses prefabrication, preassembly and modularization on applicable projects. Prefabricated and preassembled elements can include structural elements, pipe spools, equipment, pipe bridges, electrical and instrumentation. Modules have been used on turbine plants, petroleum and chemical facilities. Fluor Daniel has taken many lessons from its offshore platform experience and applied it to land-based projects.

2. General Questions regarding PPMOF

- 2.1. What are the drivers? (Schedule, Technology, Economic, Workforce)
 - Cost (TIC, unit)
 - Safety
 - Schedule
 - Labor (cost, availability, government restrictions, local economy)
 - Site conditions (climate, restricted space)
 - Owner requirement (PPMOF maximization only occurs when client drives it)
- 2.2. What are the project objectives and how do they influence the use of PPMOF?

One of the primary objectives that drive PPMOF technologies is cost. If the owner can be convinced that a PPMOF method has advantages over stick, then

Fluor Daniel believes most impediments can be overcome. Owners are convinced to utilize PPMOF when faced with a technique that is cheaper because of lower shop wage rates coupled with higher productivity, accelerated schedule due to decreased risk of weather delays, and higher quality due to a manufacturing environment.

2.3. What are the benefits?

- Neutral TIC compared to stick in most cases
- Unit cost reduction (cheaper labor, higher productivity)
- Schedule compression
- Decreased risk
- Improved change management (less changes due to offsite fab)
- Improved safety, quality

2.4. What are the impediments?

- Cultural barriers (preconceptions)
- Transportation
 - Obstructions (bridges, street furniture)
 - Road conditions/restrictions
 - Transporter requirements/limitations
 - Transporter cost/availability
 - Ocean shipping capability
 - Canal shipping capability
 - Permitting and fees
- Assembly yards (in house and out sourced)
 - Availability
 - Safety
 - Quality
 - Cost
 - Productivity
 - Utilization
 - Capacity
 - Location
- Jobsite
 - Access (water, rail, road)
 - Laydown space
 - Staging area
 - Infrastructure
 - Warehousing/offices
 - Topography
- Increased amount of up front planning and communication
- Design freeze early, decreased flexibility
- Client unwilling to open cost books, provide outage impact data (makes schedule compression benefit quantification difficult)
- Fitting modular designs for expansion of existing stick-built facilities (matching layout of existing, equipment setup for maintenance etc.)

- Convincing vendor to preassemble equipment may be difficult when his business is going well (doesn't have time to put together when production is high) Solution: Pay them more; it is usually still cheaper than stick.
- Increased management requirements
- FD may have to set up a preassembly yard across the street from a vendor to achieve benefits from preassembly
- Fixed specifications can be an impediment; some contracts requirements are written for stick (may be overcome by showing technology has been proven in other locations)

3. Recent Developments

3.1. Technology - Compared to 15 years ago, how have the following affected the use of PPMOF?

3.1.1. Equipment

Higher capacity cranes have helped with the use of PPMOF. Flat modular lifting cars that fit under the modules and are computer controlled have also improved transportation of modules.

3.1.2. Design (3D CAD, 4D CAD, etc.)

3.1.2.1. Visualization

Fluor Daniel uses 3D CAD (Intergraph PDS) extensively. They believe that 3D CAD has helped to overcome cultural barriers and increased project marketability. The software also helps with visualization questions related to operations and maintenance. Fluor Daniel believes that the use of 3D CAD has increased their use of PPMOF by providing a more convincing tool to the client and increasing design efficiency through interference reduction and other features. 3D CAD has also allowed quicker design of pipe spools.

3.1.2.2. Interference checking/field fitting reduction

PDS allows interference checking.

3.1.3. Information technology (Internet, intranet, EDI, bar coding, etc.)

3.1.3.1. Coordination

3.1.3.1.1. Lead times

Fluor Daniel's use of IT has provided opportunities for 24 hour engineering. Offices in the US, Philippines and India can work together around the clock as a result of IT. Fluor Daniel has an increased ability to communicate with its global projects.

3.1.3.1.2. Access to drawings/information

IT allows improved access to drawings and material information. The company has had the goal on some projects to become paperless, but this has not yet been completely achieved. FD believes that turnaround for RFIs has also been reduced as a result of IT.

3.1.3.2. Organization

3.1.3.2.1. Participant communication

Since communications requirements increase with the use of PPMOF, projects have benefited from the integration of team members through IT.

3.1.3.2.2. Integration of multiple sites

IT has allowed Fluor Daniel to increase the integration of multiple design offices with project sites.

3.2. Economics

3.2.1. How has the economy and labor situation played a role in the decision to use PPMOF?

Higher field labor costs, reduced availability of skilled and productive labor, and the benefits of shop work have increased the use of PPMOF. FD sees field labor as expendable and if advantages can be realized from off site work then work will be transferred off site. FD has databases of field labor that it can call upon when necessary.

4. Future of PPMOF

Not covered in interview.

5. Decision Making

5.1. How is the engineer/contractor typically involved in the decision to use PPMOF?

Fluor Daniel works early in the project to promote the use of PPMOF where applicable. A specific process is followed throughout the project,

5.2. What factors considered in analyzing possible use of PPMOF?

Unit cost is a primary factor for prefabrication and preassembly. Modularization is primarily influenced by project drivers.

5.3. What are the key criteria used to make the decision?

Project drivers, impediments and benefits.

5.4. How is preplanning involved in the decision making process?

Preplanning and increased communication is required early in the process. Management requirements increase earlier in PPMOF projects.

5.5. Who makes the decision to use PPMOF?

The client usually makes the ultimate decision to use PPMOF.

5.6. How is the decision made?

5.6.1. At what stages in a project are decisions made most successfully?

Early decisions are the most successful, typically in the later stages of conceptual design.

5.6.2. How does PPMOF affect preplanning?

Preplanning increases.

5.6.3. Are there flexibility issues?

Designs must be frozen earlier. Changes are limited due to the early design freeze. Clients also have less opportunity to change items being fabricated offsite due to proximity differences.

5.6.4. How do you determine the level of PPMOF?

Level of PPMOF is determined through analysis of the drivers, benefits and impediments to the use of PPMOF. Levels of prefabrication and preassembly are often determined by unit cost analysis. Modularization

level is usually determined by higher level drivers such as site conditions and schedule requirements.

5.6.5. Does your company have a specific decision making process for the use of PPMOF?

Fluor Daniel follows a specific process in the decision and implementation of PPMOF. The process typically begins with a modularization kickoff meeting takes place during the later part of conceptual design. The meeting includes the entire EPC team and client representatives. During this meeting, Fluor Daniel team members:

- Introduce EPC philosophy for modularization
- Give 8-hour modular presentation
- Review modularization videos
- Look at past Fluor Daniel PPMOF projects

The team then reviews lessons learned from the meeting. This review includes all disciplines, construction reps, procurement personnel, management, and client reps.

Next the EPC team completes a cost/schedule analysis.

For cost comparison:

- Determine cost removed from site
 - Design hours transferred to fabricator (Piping, structural, mechanical, electrical, instrument, civil)
 - Field work transferred offsite to vendor
- Determine additional costs
 - Added engineering (above categories)
 - Added shipping and handling costs
 - Added duty and fees
- Determine indirect costs
 - Crane size and duration requirements
 - PPMOF staff cost and support
 - Heavy haul requirements (methods, permitting)
 - Productivity differences
 - Optimize offsite man hours
- Develop cost delta from value added and additional costs
- Develop equivalent stick model for comparison
- Summarize cost differential (comparison of cost delta to stick option)

For schedule comparison:

- Analyze parallel construction impact
- Evaluate craft density and site congestion restrictions
- Calculate manpower availability
- Identify equipment lead constraints
- Conduct productivity analysis
- Compare results with stick option

Upon completion of the cost and schedule comparison, risk analyses and the level of PPMOF is determined. Risk analysis includes risks associated with the assembly yard, transportation, handling, contingencies, and bonus/penalty situations. The level of PPMOF is determined by establishing overall goals and objectives for the project. The decision process is then complete and the project moves into detailed design.

6. Information requirements and flow using PPMOF

6.1. Coordination needs

6.1.1. How is structural design handled for loading and human access considerations during different phases of the project? (Fabrication, transport, rigging, connection, testing, operation, maintenance)

The PDS models are used to design for O&M, and these representatives are involved in the design stages. 3D CAD is also used in planning for transport via lifting cars and in crane lift planning. 2D diagrams showing clearances and center of gravity have been used to plan placement of lifting cars and cranes.

6.1.2. What requirements are there for tracking the configuration, weight and center of gravity for each component?

Configuration, weight and center of gravity are tracked through configuration tables. The table is developed from a plot plan. These figures can then be used for lift planning and other considerations.

6.1.3. What are the requirements for materials management activities through the life of the project? (From initial definition of requirements through procurement, supplier technical information, expediting, fabrication, factory testing, and delivery)

FD attempts to incorporate just-in-time as much as possible. JIT capabilities typically depend on the vendor. Bar coding is also used as often as possible, mainly for structural steel, piping, some vessels and perhaps some electrical and instrumentation. Bar coding coordination with vendor systems is utilized when possible. Bar codes are linked to databases so component attributes and life during the design process.

Procurement stage requirements include:

- Coordination with assembly yard for equipment delivery
- Expediting materials for the assembly yard, project site
- Expediting modules
- Arrange transportation

6.2. What possible methods knowledge is required for the use of PPMOF?

6.2.1. (Modularization only) What level of scope is required of a module? Is it tested and operated at the fabrication facility?

For detailed design, requirements include:

- P&IDs
- Equipment and material specs
- Shipping and transport limitations

- Site constraints
- Fire protection requirements

FD typically provides the vendor with equipment lists, plot plans and the configuration tables containing modular boundaries, types of modules, weights, module sizes and other information. This allows vendors to produce a rough cost per ton before detailed design is authorized.

6.2.2. What considerations for configuration and weight are required to allow use of specific methods for transport, setting, and connection?

Lifting by crane or lifting car requires knowledge of configuration, weight and center of gravity. This is tracked through configuration tables and on lift plans.

6.2.3. (Modularization only) What are the preferred sequences for module setting, connection, and start-up?

Long lead items often dictate module sequencing. For example, a large reactor with a long lead may have surrounding modules placed first with room left to maneuver the reactor into place before final surrounding modules are installed.

6.2.4. What changes in design requirements related to operational safety and maintenance are considered?

Operations and maintenance personnel are involved early in the design process to maintain considerations for access, maintenance, etc.

6.3. What are the possible component information and attributes required?

6.3.1. (Modularization only) What are some examples of possible component systems? (Systems and members; process equipment such as pumps, compressors, heat exchangers; piping systems and components; electrical systems including equipment, raceway, and cables, and control systems)

- Structural elements
- Turbines
- Vessels
- Control centers
- Electrical wiring and instrumentation
- Piping, piperacks, spools
- Compressors
- Ladders, stairs, platforms
- Pumps
- Others

6.3.2. What are the technical attributes of components? (Function and capacity, design criteria and calculations, weight, size, center of gravity, utilities and services required, access to install and maintain, technical data from supplier describing operation and maintenance)

- Structural
 - Size and weight
 - Rigging points and limitations
 - Erection sequence

- Module interfaces
- Temporary elements
- Bolt-on components
- Equipment
 - Final assembly/ alignment instructions
 - Final installation instructions
 - Loose equipment pieces
- Piping
 - Module interfaces
 - Recommended spring/hanger support adjustments
 - Final leak test requirements
 - Final insulation requirements
 - Expansion joint shipping braces
 - Loose spool pieces
- Electrical/ Instrumentation
 - Module interfaces for conduit, wiring, and tubing
 - Final wiring and component wiring

7. Contracts/Project Delivery

7.1. What types of contracts are typically used?

For vendors, modules are often bid on a cost per ton basis. Once this cost is established, a detailed design is completed to obtain more detailed estimates.

7.2. What project delivery method is typically used? (Turnkey, DB/EPC, EPCM, DBOO, DBB, Maintenance)

FD prefers EPCM.

8. Safety/Legal Issues

8.1. How does the use of PPMOF affect safety?

PPMOF generally improves safety due to ground level and factory work

8.2. Local and site permitting (impacts on time and cost)?

Off site fabrication allows work to continue while permitting is still in progress.

8.3. How is insurance impacted?

While PPMOF does not directly impact insurance rates, any improved safety rates resulting from PPMOF can potential lower insurance by improving company records. Insurance companies do not offer lower premiums for PPMOF work.

HOWE-BAKER

Overview

Howe-Baker Engineers Inc. is firm involved in the design and construction of facilities for the industrial process industry. The company also is involved in technology development and markets the technology as part of some of its projects. Howe-Baker work totals approximately \$75-100M per year, with 50-70% of the work modular. The company is made up of about 200 engineers and 300 shop workers. Almost all contracts are fixed price.

Methods such as prefabrication, preassembly and modularization are used to varying degrees depending on the project. The company uses 3D CAD in the design process but has not found justification for its use as an animation tool. Information technology such as email and file transfer has been used to connect projects and offices. The decision process to use PPMOF tends to be based on expert opinion and evaluation of general project characteristics.

1. Profile

- 1.1. Company/Project name Howe-Baker Engineers Inc.
- 1.2. Type of industry Industrial process
- 1.3. Type of work Petroleum, gas, chemical
- 1.4. Location Main office and two fab shops in Tyler, TX; fab shop in Beaumont, TX
- 1.5. Contact information/People interviewed see above
- 1.6. How is PPMOF used the company/on the project?
Prefabrication/Preassembly
 - Pipe racks/spools
 - Structural steel
 - Equipment
 - Instrumentation
 - Electrical
- 1.7. What percentage of work is PPMOF?
50-70% of direct cost is PPMOF.

2. General Questions regarding PPMOF

- 2.1. What are the drivers? (Schedule, Technology, Economic, Workforce)
 - Minimize shutdown
 - Minimize work in “hot” areas
 - Little or no laydown space

- High weather risks
- Labor issues – not enough, not enough skilled, cost too high, union vs. non-union (union cost generally higher, involvement requirements vary by region)
- Elevated work
- Schedule concerns
- Materials - High alloy metals
- Equipment is easily modularized
- Reduce onsite peak labor
- Minimize startup costs
- Economic transportation is available
- Welding restrictions in existing facilities
- Parking availability
- Increased safety culture

2.2. What are the impediments? (Amount of preplanning, Inflexibility, Transportation, Change in project risk, Amount of project coordination, Procurement)

The main impediment to the use of PPMOF is lack of client awareness or level of knowledge regarding techniques. The impediment is mainly overcome through site visits to completed facilities and to a lesser extent, presentations of examples. 3D walkthroughs, while the company has the capability, have been deemed cost ineffective. Clients may request them at a cost premium.

Other impediments include:

- Increased structural steel required may negate cost savings
- Transportation issues
 - Northern US more constrained due to older infrastructure
- Client reluctance to share plant product cost information

3. Recent Developments

3.1. Technology - Compared to 15 years ago, how have the following affected the use of PPMOF?

3.1.1. Equipment

Advances in crane technology have aided in the use of PPMOF. Larger capacities, higher mobility and greater control have contributed. Shop fabrication has benefited from advanced welding technologies. Orbital welding stations have allowed new designs for gas reformers. Potential future technologies that would assist PPMOF include more highly automated and computer controlled welding, and pipe bending. Shop managers identified a potential for automation of standard welding of brackets and supports.

3.1.2. Design (3D CAD, 4D CAD, etc.)

Howe-Baker believes the use of 3D CAD has been owner driven. They have found that certain levels of 3D are more applicable to certain projects. Complex modular or piping intense projects benefit from a high level of 3D. Regardless of the type of project, they do not believe that 3D walkthroughs or animations are cost effective.

3.1.2.1. Visualization

3D CAD (AutoCAD) has improved visualization, especially in areas of intensive piping, electrical, or instrumentation. The software has added in the development pipe isos.

3.1.2.2. Interference checking/field fitting reduction

3D CAD aids in interference checking, especially in congested areas that were more tedious to design in 2D.

3.1.3. Information technology (Internet, intranet, EDI, bar coding, etc.)

3.1.3.1. Coordination

3.1.3.1.1. Access to drawings/information

IT has decreased lead times in request for information and contributed to shortened bid times. Email has reduced time to obtain answers to questions from days to hours. In some cases, immediate answers are possible. Bid times have decreased from 4-6 weeks to as little as 3 weeks. Staff members believe IT has obviously contributed to these decreases, but detailed quantification has not been carried out or deemed necessary.

Besides email, digital cameras have also been used on projects. Howe-Baker uses the cameras to document aspects of projects and claims a reduction in site visits to investigate concerns.

Howe-Baker has also used CD ROMs to supplement hard copies of drawings on projects.

3.1.3.1.2. Other

While IT technologies have provided advantages and improved communication on projects, Howe-Baker does not believe it has increased the number of projects handled at one time.

3.1.3.2. Organization

3.1.3.2.1. Integration of multiple sites

IT has increased the ability to conduct 24 hour engineering on projects and helped with overseas projects.

4. **Future of PPMOF**

4.1. What areas of new applications of PPMOF have the highest potential? (These can include extensions of Section 3 or other applications.)

Future applications will be driven by labor situations. Future potential PPMOF areas may result from innovations in transportation. Larger equipment may be made more applicable to PPMOF. One example would be a hydrogen plant exchanger as a module.

4.2. What are the barriers to the implementation of these new applications?

Potential barriers will include decline in wage rates or increases in field productivity. Transportation limitations may also place a cap on size restrictions.

5. **Decision Making**

5.1. How is the engineer/contractor typically involved in the decision to use PPMOF?

Howe-Baker makes the decision to use PPMOF during the bid process and presents the proposed design to the owner.

5.2. What factors considered in analyzing possible use of PPMOF?

Factors include how easily the specific plant type lends itself to PPMOF, transportation issues, and client attitudes towards PPMOF. Plant type includes equipment sizes and labor-intensive areas. Facilities with equipment fitting within the transportation envelope and increased labor intensive areas congested instrumentation, electrical, and piping all lend themselves to PPMOF. Larger equipment such as reactors and large heat exchangers may reduce the level of PPMOF.

5.3. What are the key criteria used to make the decision?

The main criteria from the client's perspective are cost and schedule. Quality is also an issue, but to a lesser extent.

5.4. Who makes the decision to use PPMOF?

Experienced Howe-Baker staff members collectively make the decision as part of a review process handled during bid development. Staff members typically include experienced upper management. On some larger projects, the project manager is also involved.

5.5. How is the decision made?

5.5.1. At what stages in a project are decisions made most successfully?

Most decisions are made early in the process, prior to the bid. The project team typically has 4-6 weeks to prepare the bid, but the trend is toward shorter cycles. Some current projects have as little as three weeks for bid preparation. Given the relatively short time frame, decisions to modularize must be made early and quickly.

Permitting issues may drive a later decision to modularize if the problem surfaces after preplanning. For example, permitting delays may move scheduled field work into the shop.

Some prefabrication and preassembly decisions can be made later in the process. The project manager may choose a method during the development of the project execution plan. The execution plan includes risk analysis which may affect the level of PPMOF used. Alterations to the execution plan after submittal to the client are kept to a minimum but are not unheard of. Some later decisions include pipe racks and plate exchangers.

5.5.2. How does PPMOF affect preplanning?

PPMOF increases preplanning. Increased planning includes checking PPMOF potential given project type and the analysis of transportation options. Preplanning may also involve owner education regarding PPMOF concepts and past projects.

5.5.3. Are there flexibility issues?

Flexibility issues depend on the client's level of approval. If the client approves a plot plan, then the design is restricted to those constraints. The use of PPMOF has not reduced the number of changes to a project. Client proximity to the work does not seem to affect flexibility. Client

representatives visit the shop and in some cases have set up temporary offices to assist in monitoring work.

5.5.4. How do you determine the level of PPMOF?

The level of modularization is determined by the project characteristics, including project drivers, equipment size, level of labor intense areas, and transportation costs. Prefabrication and preassembly is determined based on the difference between labor cost deltas and transportation costs. If the difference between shop and field labor is larger than the increased costs associated with transportation, then item or component should be prefabricated or preassembled. For example, since southern US labor rates are typically close to shop rates, it is more difficult to realize cost savings in these areas. Key differences may lie in productivity rates. Productivity is site specific and data is generally collected through surveys of the area.

5.5.5. Does your company have a specific decision making process for the use of PPMOF?

A specific procedure, flowchart or checklist was not identified. The decision process is typically handled by a group of experienced staff who evaluate the project and determine the use and level of PPMOF.

6. Information requirements and flow using PPMOF

6.1. How have new technologies affected the flow of information between the key players? (Such as internet, intranet, EDI)

IT has increased the flow of information and reduced time to obtain answers to questions. These benefits have been seen as obvious and detailed quantification was not considered necessary. Digital imaging and CD ROMs have been claimed to help spread and document information quicker and more cost effectively.

6.2. What level of information exchange is required for a PPMOF project?

Levels of information exchange vary throughout the project. The project begins with owner input on overall plot plans, processes, basic engineering, feedstock characteristics, plant height and other factors. The project then goes through a six step design process with increasing levels of information and involvement.

1) Start of Design

- a. Flow sheets, P&IDs and plot plans are developed from the owner's input
- b. Equipment specifications are identified, long lead equipment is purchased

2) Study drawings are created in 2D CAD

- a. Drawings show process lines for equipment, instruments etc.; elevations

3) Interdisciplinary collaboration

- a. 2-3 hour meeting of disciplines – electrical, instrument, piping, civil, structural, project management
- b. In-house only, constructability review and O&M considerations

- c. Disciplines provide input (For example, electrical designers provide input on the number of junction boxes required, voltage requirements, cable tray considerations, etc.)
 - d. Decisions are made based on engineering judgment
 - e. Meeting outputs = final equipment, structural and piping layout
 - f. Client is then involved in detailed design
- 4) Further design
- a. Structural design of module
 - i. Create 3D analysis package (Risa 3D, Strudl software) from study line drawings – considerations made for horizontal and vertical laydown
 - ii. Create 2D drawings from 3D analysis for fabrication
 - iii. Modular structural design tends to be less complex but requires more analysis due to more loading and lifting conditions (horizontal construction, heavy lifting)
 - b. Piping engineering
 - i. Multiple analyses (example – thermal flex analysis)
 - ii. Pipe routing based on structural model – forces communication between structural and piping disciplines
 - c. Control system development
 - i. Design of control valves, instrumentation
 - ii. Provide input to piping on controls (example – orifice beta values)
- 5) 3D Model Development
- a. Structural design is brought into model
 - b. Components are annotated with vendor information by hand – piping specs, equipment information (Automated importing of data from vendors tends to be difficult and too much detail. Level of information in vendor model is more detailed than necessary and would create a much larger and cumbersome 3D model.)
 - c. Plan, elevation, section and detail drawings are created
- 6) Interdisciplinary Squad Check
- a. Information from step 5 are checked and evaluated by the team
 - b. Design is given to the customer for review and comment
 - c. Final design is exported for construction
 - i. Pipe isos created for shop
 - ii. Bill of materials generated
 - iii. Structural designs for foundations sent to site, shop details to shop

Pipe design and information flow is usual the critical activity for a project. Howe-Baker does not believe PPMOF necessitates and major increase in engineering for projects. Increases are observed in structural and electrical, but not in piping, controls, or equipment.

6.3. Are there standards for information exchange?

Howe-Baker uses official hard copies of drawings for projects. It is believed that electronic signatures and paperless projects may be the standard in the future.

6.4. What are the possible component information and attributes required?

6.4.1. (Modularization only) What are some examples of possible component systems? (Systems and members; process equipment such as pumps, compressors, heat exchangers; piping systems and components; electrical systems including equipment, raceway, and cables, and control systems)

A typical modular project contains 25-30 pieces of equipment. Smaller projects may have 15-20. Equipment examples include vessels, pumps, compressors, blowers, gas reformers, and heat exchangers. Systems include structural (temporary and permanent), piping (including unusual alloys), instrumentation/controls (valves), electrical (junction boxes, cable trays), and civil (foundations, etc.).

7. Contracts/Project Delivery

7.1. What types of contracts are typically used?

Virtually all of Howe-Baker's work is fixed price, lump sum.

7.2. How is payment made?

7.3. What project delivery method is typically used? (Turnkey, DB/EPC, EPCM, DBOO, DBB, Maintenance)

Turnkey is preferred, allowing the company easier control of pricing and profits. Subcontracting is kept to a minimum.

8. Safety/Legal Issues

8.1. How does the use of PPMOF affect safety?

8.2. Local and site permitting (impacts on time and cost)?

Permitting delays can drive the use of PPMOF.

8.3. Proprietary information retention?

Since Howe-Baker is involved in technology development and sales, the use of PPMOF helps them to protect these proprietary technologies. Sensitive components, such as parts for a hydrogen plant, can be assembled in the shop and covered as part of a preassembly or module.

References

- CII (1992). *MODEX User's Guide*. Publication 29-1. Construction Industry Institute, The University of Texas at Austin.
- Deemer, G. R. (1996) "Modularization reduces cost and unexpected delays." *Hydrocarbon Processing*. October 1996.
- Eickmann, J. A. (1999). *Prefabrication and Preassembly Trends and Effects on the Construction Workforce*. M.S. Thesis. The University of Texas at Austin.
- Fisher, D. J., and Skibniewski, M. (1992). "Computerized Decision Support for Modularization of Industrial Construction." SD-72. Construction Industry Institute, The University of Texas at Austin.
- Gibb, A. G. F. (1999). *Off-site Fabrication: Prefabrication, Pre-assembly and Modularisation*.
- Hornaday, W. C. (1992). *Computer Aided Planning for Construction Heavy Lifts*. M.S. Thesis. The University of Texas at Austin.
- Hsieh, T. Y. (1997). "The Economic Implications of Subcontracting Practice on Building Prefabrication." *Automation in Construction*. 6(3).
- Kupitz J. and Goodjohn A. (1991). "Trends in Nuclear Power Reactor Design and Technology." *Energy*. 16(1/2).
- Mulva, S. P. (1996). *Best Practices Impacts on Construction Project Costs*. M.S. Thesis. The University of Texas at Austin.
- Murtaza, M. and Fisher, D. J. (1994). "Neuromodex – Neural Network System for Modular Construction Decision Making." *Journal of Computing in Civil Engineering*. 8(2).
- Murtaza, M., Fisher, D. J., and Skibniewski, M. (1993). "Knowledge-Based Approach to Modular Construction Decision Support." *Journal of Construction Engineering and Management*. 119(1).
- Retik, A. and Warsawski, A. (1994). "Automated Design of Prefabricated Building." *Building and Environment*. 29(4).
- Shaked, O. and Warsawski, A. (1992). "CONSCHEDE: Expert System for Scheduling of Modular Construction Project." *Journal of Construction Engineering and Management*. 118(3).

- Smock, R. (1992). "Fast-track, Low Cost Construction Starts with the Owner." *Power Engineering*. 96(2).
- Stubbs, D. L. and Emes, P. D. (1990). "Prefabricating a Process Plant." *Mechanical Engineering*. 112(11).
- Tatum, C. B., Vanegas, J. A., and Williams, J. M. (1987). "Constructability Improvement Using Prefabrication, Preassembly, and Modularization." SD-25. Construction Industry Institute, The University of Texas at Austin.
- Vanegas, J. A. and Hastak, M. (1995). "A Multimedia Decision Support System for Evaluating the Use of Modularization in Industrial Construction." *Computing in Civil Engineering*. June 5-8, 1995.
- Warszawski, A. (1990). *Industrialization and Robotics in Building*.

**DEVELOPMENT OF A DECISION-SUPPORT TOOL FOR
PREFABRICATION, PRE-ASSEMBLY, MODULARIZATION
AND OFF-SITE FABRICATION**

by

Carl T. Haas
Jongchul Song

A Report to
The Construction Industry Institute
The University of Texas at Austin

Under the Guidance of
The PPMOF Research Team
PT 171

from
The Department of Civil Engineering
University of Texas at Austin
Austin, Texas

August 2002

Copyright © 2002 Construction Industry Institute™.

The University of Texas at Austin.

CII members may reproduce and distribute work internally in any medium at no cost to internal recipients. CII members are permitted to revise and adapt this work for the internal use provided an informational copy is furnished to CII.

Available to non-members by purchase; however, no copies may be made or distributed and no modifications made without prior written permission from CII. Contact CII at <http://construction-institute.org/catalog.htm> to purchase copies. Volume discounts may be available.

All CII Members, current students and faculty at a college or university are eligible to purchase CII products at member prices. Faculty and students at a college or university may reproduce and distribute this work without modification for educational use.

Printed in the United States of America.

Development of a Decision-Support Tool for Prefabrication, Pre-assembly, Modularization, and Off-site Fabrication

Executive Summary

Prefabrication, preassembly, modularization, and off-site fabrication (PPMOF) have become more viable with recent advances in design and information technologies and offer a substantial opportunity to improve project performance. Successful implementation of PPMOF requires systematic analysis and early decision-making based on project factors. Preliminary research by the CII PPMOF project team updated those factors influencing PPMOF decisions and developed a decision framework. Continuing the preliminary research, this study identified the current decision-making paradigm for evaluating the applicability of PPMOF. The team refined the preliminary decision framework and developed a computerized tool to aid project teams in the decision-making process. The developed tool was validated by potential users in the industry. A description of the tool and guidelines to implementing the tool are presented in this report.

Development of a Decision-Support Tool for Prefabrication, Pre-assembly, Modularization, and Off-site Fabrication

Table of Contents

Executive Summary.....	i
List of Tables.....	iv
List of Figures.....	v
Chapter 1: Introduction.....	1
Overview	1
Objectives & Scope	3
Methodology.....	4
Structure of Report	5
Chapter 2: Literature Review & Background.....	6
Literature Review	6
Decision Methodologies.....	11
Chapter 3: Methodology.....	20
Overview	20
Requirements Analysis.....	23
Analytical Method & Software Selection.....	24
Prototype Design	25
Beta Testing and Validation	26
Final Construction of the Tool & Documentation.....	26
Chapter 4: Description of the Decision Tool.....	28
Overview	28
Strategic Level I Analysis	32
Strategic Level II Analysis	35

Tactical Level Analysis	46
Chapter 5: Validation Results and Modifications	49
Overview	49
Validation Results	49
Modifications.....	51
Chapter 6: Conclusions and Recommendations.....	53
Conclusions	53
Recommendations	54
Appendix A: Detailed Questions for Strategic Level II Analysis	56
Category 1 – Schedule.....	57
Category 2 – Cost.....	58
Category 3 – Labor.....	59
Category 4 – Safety	60
Category 5 – Site Attributes	61
Category 6 – Mechanical Systems	62
Category 7 – Project and Contract Types.....	63
Category 8 – Design	64
Category 9 – Transportation & Lifting Requirements	65
Category 10 – Supplier Capability	66
Appendix B: Research Team Members and Affiliations	67
Appendix C: Beta Test Survey and Summary of Results.....	69
Survey Cover Letter	70
Questionnaire Form	72
Summary of Results	74
References	76

List of Tables

Table 2.1: Major Components of DSS and ES (adapted from Bidgoli 1989).....	13
Table 2.2: Comparison of DSS and ES (adapted from Bidgoli 1989)	14
Table 2.3: Decision-making Process & Technologies of MODEX & Neuromodex	15
Table 3.1: Team member companies and institutions.....	20
Table 4.1: Strategic Level II Analysis Categories.....	35

List of Figures

Figure 2.1: Use of Prefab & Preassembly in construction (Haas et al. 2000).....	9
Figure 3.1: Flowchart of Overall Research Methodology	21
Figure 4.1: Roadmap for PPMOF Decisions (adapted from Fagerlund 2002).....	29
Figure 4.2: PPMOF Strategic Decision Tool Introductory Worksheet	31
Figure 4.3: Strategic Level I Analysis	34
Figure 4.4: Evaluation Process for Strategic Level II Analysis	36
Figure 4.5: Example of Assigning Weight Factor Values to Ten Categories	37
Figure 4.6: Example of Detailed Questions of Strategic Level II Analysis	39
Figure 4.7: Example of Strategic Level II Evaluation Summary	40
Figure 4.8: Interpretation of the Final Score for Strategic Level II Analysis.....	41
Figure 4.9: Example Reports of Extremes – Factors Most Strongly Supporting PPMOF	42
Figure 4.10: Example Reports of Extremes – Factors Most Strongly Against PPMOF	43
Figure 4.11: Example of Selecting Pages to Print.....	45
Figure 4.12: Example Selected Pages to Print.....	45
Figure 4.13: Example of Case Option for Tactical Analysis.....	47
Figure 4.14: A Structure for Cost Comparisons among PPMOF Alternatives	48

Chapter 1: Introduction

OVERVIEW

Owners demand high levels of value, safety, quality, productivity, and performance in their capital projects for their competitiveness and profitability. They are still expecting effective and efficient project delivery with tight cost and schedule control. In addition, owners face a current and projected shortage of skilled labor. Prefabrication, preassembly, modularization, and off-site fabrication (PPMOF) can help overcome such project challenges and, properly used, offer a substantial opportunity for improved project performance (Tatum et al. 1987).

However the use of PPMOF can also bring about many changes in projects and place new demands or complexity on project organization, engineering and procurement, planning and monitoring, coordination and communication, and transportation, with decreased change flexibility. Thus, taking full advantage of the opportunity presented by PPMOF requires weighing these implications against the potential benefits. To evaluate the potential benefits and impediments to implementing PPMOF on their projects, managers considering PPMOF need a systematic method for analysis and decision-making on the applicability of PPMOF.

Also, an early decision to use these methods is important to maximize the potential benefits. While many decisions to pre-assemble or prefabricate components can be made during or after the detailed design phase, modularization decisions made at the start of detailed design result in large cost premiums for additional engineering. Since modularization shipping envelopes and interfaces typically dictate many constraints of detailed design, early decisions are generally more successful.

With advances in design and information technologies in recent decades, PPMOF have become more viable. According to a study performed by the Center for Construction Industry Studies at the University of Texas, the use of prefabrication and pre-assembly has increased 86% over the preceding fifteen years (Haas et al. 2000). In the mean time, key factors influencing the decision-making on the use of PPMOF, including new technologies and a changing construction environment, have expanded and changed. These changes have driven the need to address the impact of recent technological advances on the use of PPMOF and decision-making alike.

New technologies such as computer controlled fabrication equipment, 3D CAD, electronic transfer of data, and the internet have provided opportunities for advances in design efficiency and coordination. Also, to exploit the capabilities of 3D CAD technology to ensure accuracy, precision, and visualization, recent trends in construction emphasize smaller scale assemblies. Apart from 3D CAD, automated positioning and other technologies show great promise to transmit of a “just-in-time” order for a rebar assembly to a fabrication plant and have that plant deliver the assembly within 24 hours, from scrap metal to final assembly and delivery (Fagerlund 2001). The capability and beneficial use of information technology on design and construction projects is advancing rapidly. The resulting ability to develop CAD models is a major advantage for the potential use of modularization and pre-assembly, for the CAD models include knowledge required for use of PPMOF along with extensive engineering, procurement, and construction information about all the components of a plant (Fagerlund 2001). The automation made possible with CAD and other information technologies provides more opportunities to PPMOF that by nature contain more physical and organizational interfaces, than with conventional methods.

Given the challenges faced by the industry coupled with the impact of recent revolutionary technological advances, PPMOF presents a substantial opportunity for improved project performance. Nonetheless, the industry in general has not fully recognized the potential for project improvements from the use of PPMOF. This has been primarily the result of a lack of awareness of the benefits and a tendency to postpone early decisions on the feasibility of PPMOF, which can preclude their use. There emerges a clear need for a decision-making framework that encompasses all factors driving or impeding implementation, reflecting the technological impact and the industry challenges.

OBJECTIVES & SCOPE

Preliminary research identified state-of-the art PPMOF practices, updated those factors influencing PPMOF decisions, and developed a decision framework to assist project teams in considering possible use of PPMOF on industrial projects (Fagerlund 2001).

The research effort described in this report continued the preliminary research and sought to develop a tool to facilitating the decision-making process for evaluating the use of PPMOF on particular projects based on factors identified. In support of this main objective, the following specific objectives guided this research:

- Identify the decision-making process used by the industry;
- Identify the needs and requirements of potential users of the tool;
- Determine the analytical methods suitable for the decision-making paradigm;
- Help identify specific factors driving or impeding the use of PPMOF on the project under evaluation;

- Validate the prototype tool and incorporate validators' suggestions for improvements into the decision framework as well as the final construction of the tool;
- Develop guidelines to help implement the tool developed.

The research covers the decision-making process for the use of PPMOF on a particular industrial construction project. The decision-making process includes the decision framework and the computerized tool (analytical method & user interface) to aid owners, engineers & contractors, subcontractors, and suppliers in evaluating the applicability of PPMOF. The process also includes the guidelines to implement the tool.

METHODOLOGY

Once the research team developed the preliminary decision framework, the development process for the tool began with requirements analysis. The team reviewed the relevant tools that the literature provided, tried to define specifically what the industry users want or need from such a tool, and considered whether development of such a tool is feasible given the financial, time, and other constraints of the research project.

With the user needs and requirements defined, the team selected an analytical method suitable for evaluating the applicability of PPMOF on a particular project, and a compatible software for embodying the analytical method and user interface. Then a prototype was designed in an iterative manner before the final construction of the tool. The developed prototype tool was subsequently beta tested by potential users in the industry and eventually evolved into the final tool. Finally, guidelines were documented to help users implement the tool.

STRUCTURE OF REPORT

This report is organized in six chapters. Chapter 1 provides an overview of PPMOF and a need for the proposed tool, and describes the objectives, scope, and methodology of the research. Chapter 2 presents an overview of past studies on the use of PPMOF, including the preliminary results of this research, and then provides some background on relevant decision methodologies and discusses the issues related to the identification of a suitable decision method. Chapter 3 describes the research methodology for developing the proposed tool. Chapter 4 provides the description of the developed tool, and Chapter 5 presents validation results and modifications made to the tool. Finally this report presents the conclusions reached and recommendations for further research.

Chapter 2: Literature Review & Background

LITERATURE REVIEW

Past research studies have determined that the appropriate use of PPMOF has the potential to positively impact project performance (Tatum et al 1987; Haas et al. 2000). While these studies investigated the practices of PPMOF and delineated factors to consider when evaluating the use of PPMOF, other research efforts were concerned primarily with the development of the decision-making systems, model, or framework to aid in evaluating the applicability of PPMOF on a particular project (CII 1992; Murtaza et al. 1993, 1994; Cigolini & Castaliano 2002).

A study conducted by CII in the mid 1980's identified and analyzed practices at the time in the use of PPMOF in both industrial and building construction projects (Tatum et al. 1987). The research then identified the forces prompting their use and implications for a project. Although the applications of PPMOF studied included a wide range of both industrial and building projects, many similar forces were found to drive the use of PPMOF:

- Adverse site and local area conditions
- Competitive conditions
- Specialized building or process technology
- Advantages of manufacturing conditions
- Demanding schedule
- Owner or regulatory demands
- Specialized design requirements
- Modular design or repetitive units
- Potential cost savings

The project implications of PPMOF that the research found are either those impacting the overall project or those focused on specific functional activities:

- Project feasibility and risk
- Project organization
- Project planning and progress monitoring
- Project coordination
- Project results
- Design scope and activities
- Procurement operations
- Fabrication, transportation, and construction operations
- Testing and start-up operations
- Facility operation

This early study also described general processes used to evaluate and implement PPMOF, and developed guidelines for the effective use of PPMOF. It found that the processes for evaluating the use of PPMOF were highly project specific, ranging from very systematic studies of feasibility, cost, and schedule for several alternatives to quick decisions based on intuition and judgment (Tatum et al. 1987). Arguing that it is not possible to define a scope of a project without considering PPMOF, the research emphasized the fundamental role PPMOF plays in defining a project.

A follow-up research project developed MODEX, a DOS-based expert decision support system, for use by various professionals in the construction industry which aided in determining the feasibility of an industrial project for modularization. Designed to evaluate the feasibility of using modular construction technology for a particular process or power plant project, the system performs feasibility analysis based on various factors divided into five influencing factor categories: plant location; labor-related; environmental and organizational; project characteristics; and project risks (CII 1992). This system also performs an economic analysis to determine the impact of modularization on cost and schedule, and provides the approximate cost saving or increase that modularization is expected to produce in the project under consideration.

Later study validated this system to determine if the recommendations provided by MODEX match with those of professionals in the construction industry (Murtaza et al. 1993). A statistical analysis performed concluded with a

91% confidence that the results obtained from the validators and MODEX were not significantly different.

A more advanced software tool, called Neuromodex, was also developed based on the neural network architecture to handle the inexact and incomplete inputs. The neural network-based decision-making system uses as inputs the same decision factors as MODEX and provides the final conclusion for a modularization decision. The results obtained from the system were compared with the recommendations provided by experts. The statistical tests performed to validate the system showed, though limited to ten cases, that neural network results were accurate (Murtaza et al. 1994).

A study of prefabrication and preassembly was conducted by the Center for Construction Industry Studies (CCIS) at the University of Texas in 1998 to estimate recent changes in the use of these methods. Based on an extensive survey of over 27 construction professionals with a combined experience of over 700 years, this research found that the use of these two methods had nearly doubled, increasing by 86%, over the preceding fifteen years (Haas et al. 2000). Significant increased use occurred in the areas of equipment, instrumentation, ironwork, mechanical, piping, and structural assembly, as shown in Figure 2.1.

The study performed by CCIS reported that for prefabrication and preassembly work, productivity and safety levels were higher, skill levels were the same, and wage levels are lower, compared with traditional stick-built construction. According to this study, the three main drivers of the use of prefabrication and preassembly are schedule, workforce issues, and economic factors, with schedule being the most important. This study found that prefabrication and preassembly may also reduce the overall project cost, while increasing craft productivity, improving quality, and reducing labor rates. On the other hand, impediments to prefabrication and preassembly were additional

preproject planning and project coordination; increased transportation difficulties; greater inflexibility; and more advanced procurement requirements.

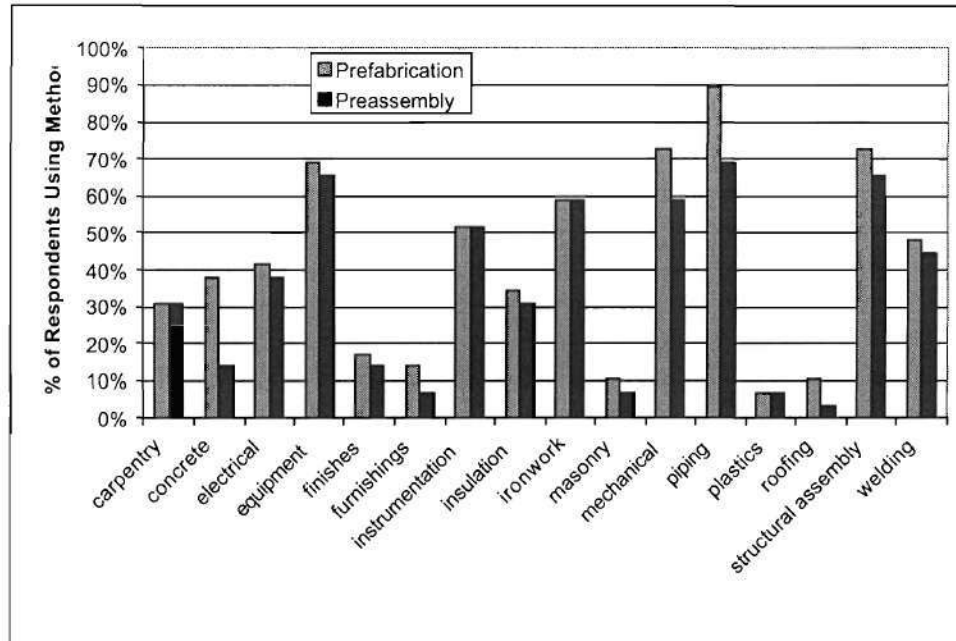


Figure 2.1: Use of Prefab & Preassembly in construction (Haas et al. 2000)

Most recently, a quantitative model was proposed to determine cost variance between stick-built and modular construction and aimed at filling the gap between the economic analysis of MODEX and the actual estimation process (Cigolini & Castaliano 2002). First, the model identified the ‘construction-related’ cost items that can be influenced by modularization, including transportation cost, facilities cost, and cost of consumable resources (i.e., water and electric power). The identified cost items, split according to project location perspective (i.e., final site, mod-yards), are then quantified using the basic module data (module weight, size and surfaces, pipe materials, equipment, and man-hours needed to complete each module). Finally, the model determined the cost variance under the modular and traditional approaches by comparing the cost items by areas where costs

originated. For example, the overall facilities cost difference comes from the sum of facilities cost (at each mod-yard location) minus the cost of the same facilities if fabricated on the final site. However, the model has not considered engineering and procurement-related costs, for example, design man-hours increased by modularization.

Through the above studies, the drivers, benefits, impediments, and their effects on decision-making for PPMOF have been well documented. Further improvement is however needed to address the impact on these factors of recent revolutionary advances in design and information technologies, including 3D CAD, tracking, and automated positioning/locating.

With this motivation, a preliminary research effort identified state-of-the-art PPMOF practices, updated those factors influencing PPMOF decisions, and developed a decision framework and a roadmap to assist project teams in considering possible use of PPMOF on industrial projects (Fagerlund 2001). The decision timing map identified recommended points in the project life cycle to determine the level and scope of PPMOF, and enabled the use of the framework to allow for variable timing of decision-making. The preliminary research also identified the information technologies that help to overcome added requirements of design, coordination, communication and organization for implementing PPMOF.

The research presented in this report continues with the preliminary research, and based on the decision framework, will develop a tool to evaluate the applicability of PPMOF on particular projects.

DECISION METHODOLOGIES

The previous section presented an overview of past studies on the use of PPMOF, including the preliminary results of this research. Focusing on the decision-making process, this section discusses the issues related to the identification of a suitable decision method in the PPMOF domain after presenting some background for relevant decision methodologies.

Before developing an effective decision tool, several questions have to be answered to select appropriate decision methodologies for application to a particular problem, such as:

- What's the decision to be made? What are the nature and characteristics of the decision?
- Who is going to make the decision and how? How will a computerized tool or system affect their decision-making?
- When should the decision be made?

For the modularization decision problem, the construction industry answers the above questions surprisingly consistently, as hinted by the literature. Owners' management, project managers, construction managers, or engineering managers should make a decision whether to use a conventional "stick-built" method or some degree of PPMOF for a particular project, at the early stage in a project life cycle somewhere from business planning to conceptual design. This decision depends entirely on the individual project characteristics and involves a multiattribute/multicriteria decision-making process (Murtaza 1993). Thus, the decision problem for a particular project is one of a kind and has no precedence.

Furthermore, a proper decision-making process, encompassing not only modularization but also preassembly, prefabrication, and off-site fabrication, should allow for variable timing of decision-making since PPMOF provides a spectrum of potential implementation choices rather than an "all or nothing"

decision (Fagerlund 2002). The decision timing considerations often depend on the level or type of PPMOF. For maximizing benefits of PPMOF, while earlier decisions are best for any use of PPMOF, modularization and complex preassembly require earlier decision than do simple preassembly and prefabrication (Fagerlund 2002). Specifically, the use of modularization is often decided early during preproject planning, and other levels of PPMOF are mainly considered as late as during detailed design. The feasibility of modularization depends on the specific project, organizations involved, and social, legal, and environmental conditions (Murtaza 1994), and a modularization decision is often based on subjective evaluation of experienced personnel, not on cost information which may be given by computational procedures. A computerized decision tool that is mostly likely to be used by the decision-makers is one that effectively deals with the very nature of PPMOF decisions.

There were several research efforts to develop a computerized tool to aid decision making about PPMOF – MODEX and Neuromodex (Murtaza 1993, 1994). Decision methodologies applied to the tools draw upon technologies related to Artificial Intelligence (AI) that aspires to emulate human thought behavior. Modex is built on a hybrid expert system, integrating a component of decision support systems (DSS) into expert systems (ES). A step forward, Neuromodex takes an adaptive pattern recognition approach based on artificial neural network. To facilitate the discussion on decision methodologies of the tools, it is necessary to present an overview of related computer technologies.

Both DSS and ES represent computer-based systems for decision support, a means for aiding the decision-maker's problem solving process, the substantial part of which is decision-making. As Adelman explains, DSS are interactive computer programs that utilize analytical methods, such as decision analysis, optimization/non-optimization algorithms, for developing models to help decision-makers formulate alternatives, analyze their impacts, and interpret and

select appropriate options for implementation. Similarly, ES are interactive programs designed to emulate the problem solving process of one or more experts in a particular problem domain (Adelman 1992). DSS and ES have similar major components, as shown in Table 2.1:

Table 2.1: Major Components of DSS and ES (adapted from Bidgoli 1989)

Decision Support System	Expert System
Data Base	Knowledge (Rule) Base
Model Base	Inference Engine
Dialog Management	User Interface

Yet, DSS and ES present the differences in many ways that should be highlighted. While DSS use quantitative data, models, and algorithms, ES work with heuristics data, sometimes referred to as “rules of thumb.” Heuristic does not imply formal knowledge but rather finds a solution to a problem without following a rigorous algorithm. In other words, the ES’s underlying process is represented by IF – THEN rules. For instance of MODEX initial feasibility analysis, if the total weighted score is less than a predetermined threshold, then use of a non-modular method is suggested to the user. On the other hand, DSS address general, unstructured, or partially structured decision problem, which is unique in nature and mostly non-recurring, such as in conflict resolution between entities (Hipel et al. 2001) and feasibility of modularization on a particular construction project. In contrast, ES deal with a specific, well-defined problem domain, which has been solved by human experts before or presents a well-defined procedure for proposing a solution, but involves several hundred to thousand rules and a complex logic. In general, DSS tries to support a decision-maker; ES aims at replacing a decision-maker. DSS attempt to provide

information that helps the user make a decision; ES attempts to make an actual decision in situations where there are not enough experts to go around by mimicking a human expert. Table 2.2 summarizes comparison between DSS and ES.

Table 2.2: Comparison of DSS and ES (adapted from Bidgoli 1989)

	DSS	ES
Main objective	Improve effectiveness of decision-making	
Orientation	Support a decision-maker Improve/expedite decision-making process	Mimic human experts Make actual decisions
Typical users	Decision-makers/ Experts	Less experienced personnel
Problems addressed	General Unstructured Semi-structured Non-recurring	Specific Well-defined Solved by experts Repetitive, routine
Operation	Algorithmic Quantitative	Heuristic Qualitative/quantitative
Output	Alternatives with analyses of their impacts	Conclusion/recommendation with explanation

The overview of DSS and ES puts MODEX into perspective, and the specific ES product lends itself to examination from philosophical, behavioral, and pragmatic standpoints. Then, attention is turned to Neuromodex. Table 2.3 shows how MODEX and Neuromodex structured the decision-making process and what computer technologies they involved (for modularization decision, not all the levels of PPMOF).

Table 2.3: Decision-making Process & Technologies of MODEX & Neuromodex

	MODEX	Neuromodex
Decision-making Process	Underlying Computer Technology	
Initial Feasibility Analysis	Expert system	n/a
Detailed Feasibility Analysis	Expert system	Neural network
Economic Analysis	Decision support + expert systems	n/a

For the first two steps, MODEX asks the user a series of qualitative questions regarding various factors that can influence the feasibility of modularization on a project under consideration. Calculating the total weighted score, MODEX makes a “recommendation,” either conventional or modular, with the level of confidence of the advice, based on the rule base of the expert system. In the calculation of the total weighted score, relative weights on factors and categories are given by MODEX, not by the user. For the final stage of analysis, economic study, the user gives MODEX estimated project cost/schedule, and in turn, MODEX gives the user cost savings (or loss) and schedule reduction possible by adopting some degree of modularization. This analysis requires some cost information processing and is efficiently performed by the hybrid architecture. The integrated approach combines a knowledge base with a data base. The knowledge base contains decision rules on modularization, and the data base stores cost summary of realized modular construction projects and their relative cost differentials (CII 1992). As powerful as its capabilities are, MODEX raises several issues.

First, its ability as an expert system to capture expertise, which often cannot be articulated by the human experts themselves, is questioned. Besides, MODEX packages “expertise” in a piece of software (into the knowledge base)

for use by individuals without the knowledge to critically evaluate the system's recommendation. As discussed earlier in this section, a modularization decision problem is quite unique, and evaluation of its feasibility on a particular project is of a judgmental nature, "not structured, and there was no single individual, or even multiple individuals, who could be considered the true expert or experts" (Murtaza 1994). It is however safer to say that there is no such expertise made available to an expert system. Since human experts follow relatively few rules explicitly and it is difficult to state a complete and accurate set of rules to capture the expertise (Kamarthi et al. 1992), elicitation of knowledge in the form of rules from a domain expert is also difficult. Moreover, the developer of MODEX and Neuromodex added, "there was no certainty whether the decisions made in the past about the modularization were correct." If this is the case, such problems as modularization feasibility that have not been previously solved by human experts, or in which there is room of disagreements among the experts, are not candidates for expert systems application.

Second, the expert system is not fairly "transparent," especially from the potential user's viewpoint. In fact, some industry team members feel it is like a "black box." Even though it would have been possible, MODEX does not tell the user why it made a particular recommendation or how particular advice was generated. Besides, for calculating cost savings in the economic analysis, MODEX uses an analytical method which the users are often not accustomed to and structures the cost comparison problem differently than the industry usually does. MODEX requires the user to "know the distribution of the total project costs (for conventional construction) among the ten categories [of cost components]" and "define the percentage increase or decrease that each category changed for using modular construction." This process may not easily fit into an organization's formal/informal operational procedures for computing cost differences.

An alternative to the expert systems approach was suggested by Neuromodex taking the pattern recognition approach of artificial neural networks (NN). To put it simply, Neuromodex maps from input patterns to output patterns. Like human experts, it uses several decision factors of a particular project, which are categorized into location, labor, environmental/organizational, etc., as a set of inputs to form a pattern, then associate the input pattern with one of output patterns: conventional; low partial modularization; high partial modularization; extensive modularization (Murtaza 1994). Thus, the output represents level of modularization applicable on the project, which constitutes the decision that should be made by human experts. To be able to recognize input patterns and produce outputs, the neural network must be trained with a certain set of training examples – simply, some input examples and optionally, the corresponding known outputs – so that it is capable of correctly associating all example patterns with their desired output.

The major reason for using the neural network approach stems from the fundamental drawback of the expert systems approach that the human decision-maker is not aware of what rules motivates his or her decision on modularization (Burke 1991), as discussed above. This rationale for Neuromodex is consistent with Moselhi's view that construction experts in reality do not reason to produce reliable decisions based on partial cues (Moselhi 1991). Construction experts rather use these "rules" to try to explain why they arrived at those decisions. They might even fail to rationalize their decisions when they consider a good number of interrelated factors in parallel, as with the PPMOF decision problem. The neural network learns the implicit knowledge, expertise, or rules from the training example which could be elicited from experts without the need for asking how and why. Thus, Neuromodex seems to rectify the knowledge acquisition problem with MODEX, and as a decision tool it advances one step forward. Nonetheless, there arise some other issues.

To be able to exploit the strengths of Neuromodex, numerous training examples of modularization decisions should be made available. The ability to train the network depends on the availability of a large amount of historical data (Burke 1991). Indeed, numerous past solutions are in need in the modularization domain. 40 cases were used to train Neuromodex; in the NN application for selecting the most appropriate bidders for a particular project, 80 cases were collected from only one organization for training (Taha 1998). The cost of labeled data – the association of a ‘correct’ output with an input pattern – can outweigh the benefit of using an effective neural network (Burke 1991). Without being efficient, a decision-maker cannot be effective, either. Apart from the possible expenses, decision-makers may not easily accept Neuromodex (as well as MODEX) aspiring to imitate human intelligence. Their willingness to cast the PPMOF problem into a pattern recognition paradigm is not presumable.

In conclusion, the development of MODEX and Neuromodex is “technology-driven” instead of “requirements-driven.” As a matter of fact, most of the ten companies investigated as part of the preliminary research are using in-house expertise and relied on the judgment of experienced project managers, rather than utilizing tools already on the market (Fagerlund 2001). Only one of the companies makes use of MODEX to compliment (not to replace) in-house expertise. These companies agreed that a decision tool would be useful for determining feasibility of PPMOF both for internal and client ‘justification.’ To be useful and effective in evaluating the applicability of PPMOF, such a tool should:

- serve as a means to facilitate a decision process dialogue, rather than assuming the role of an “answer machine”
- provide transparency to invoke decision-makers’ judgment on relative importance of decision factors and to help them sort out what factors drive

or impede the use of PPMOF on the project under consideration, rather than representing a “black box.”

Based on the preliminary research introduced in the Literature Review, the proposed tool was developed to meet this need. The development efforts are focused on the Strategic Level analyses, due to the timing constraint of the research. Besides, later decisions at the tactical level are more likely governed by the organization's standard operation procedures, as it is essentially a cost comparison between the conventional method and any level of PPMOF.

Chapter 3: Methodology

OVERVIEW

The tool described here was developed as part of the research efforts of CII project team 171, and is based on the preliminary decision framework introduced in the previous Literature Review section. The team consisted of representatives from the construction industry and academic institutions. Industry members representatives ranged from owners to contractors to design firms to suppliers, each experienced in the use of PPMOF, typically on industrial projects. Academic members represented three institutions and each had prior research experience with PPMOF. Table 3.1 lists the companies and institutions participating in the development, and Appendix B lists the team members and their affiliations. Past member companies participating in the preliminary research include Jacobs Applied Technology, Lester Building Systems, LTV Steel Company, Stone & Webster Engineers & Constructors, and Jacobs Applied Technology. The overall research effort lasted more than two years with the last year spent developing the tool and documenting other research products.

Table 3.1: Team member companies and institutions

• BE&K, Inc.	• Rust International Corporation
• Chicago Bridge & Iron Company	• Lockwood Greene E&C
• Eli Lilly and Company	• Stanford University
• Eichleay Engineers & Constructions, Inc.	• The University of Texas at Austin
• Georgia Institute of Technology	• U.S. Army Corps of Engineers
• Kvaerner Process	• U.S. Department of State
	• U.S. Steel

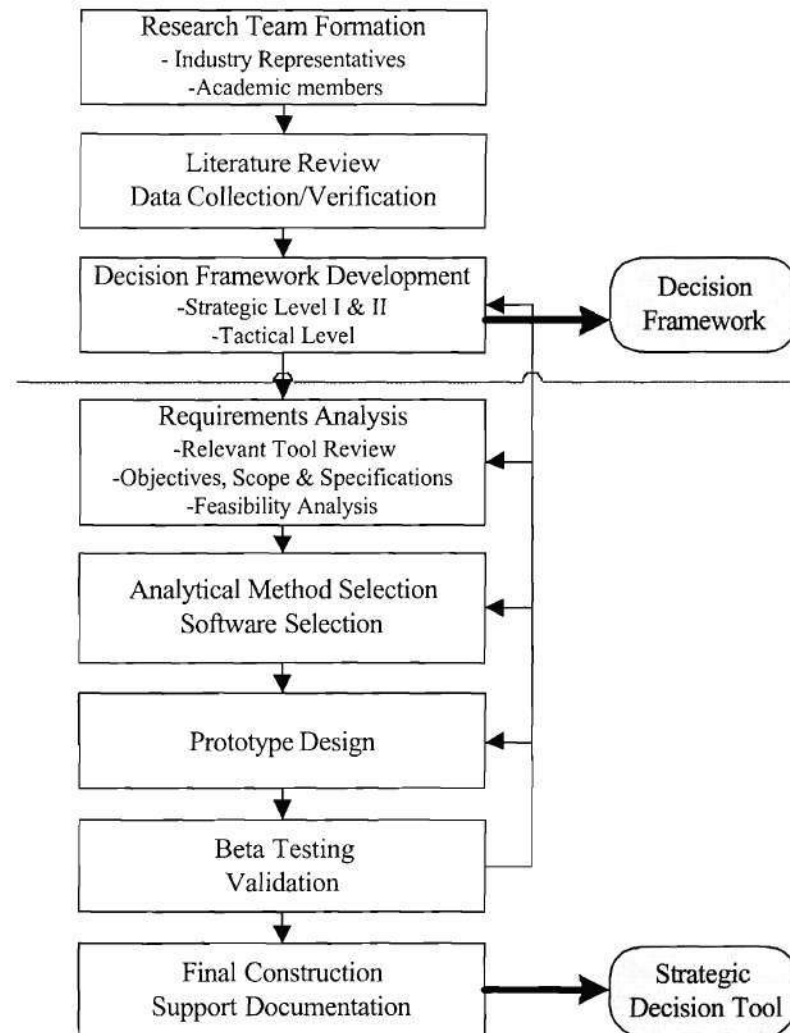


Figure 3.1: Flowchart of Overall Research Methodology

The methodology for the overall research followed several steps, as shown in the flowchart (see Figure 3.1). Once the research team developed the preliminary decision framework, the development process for the tool began with requirements analysis. The team reviewed the relevant tools the literature

provided, tried to define what the industry users want or need from the tool, and considered whether development of such a tool was feasible given the financial, time, and other constraints. With the user needs and requirements defined, the team selected an analytical method suitable for evaluating the applicability of PPMOF on a particular project and a compatible software for embodying the analytical method and user interface. Then a prototype was designed first, before the construction of a complete tool. The developed prototype tool was subsequently beta tested by potential users in the industry and eventually evolved into the final tool as new features were added and existing features upgraded. Finally, guidelines were documented to help users implement the tool.

As Figure 3.1 illustrates, all steps of the development process can be combined into one phase that continued in an iterative manner. The development process emphasized the application of a prototyping approach that involved iteration, test and evaluation, and subsequent refinement (Adelman 1992). The approach was rewarding since it would be easier for users to answer the question 'How do you like the tool?' than the question 'How would you like it?' Since requirements of the tool may not be accurately represented without users interacting with a working model of the tool, prototyping helped quickly develop such a model, get the users' reaction to it, and keep the development process on track. Involvement of users as a design team was instrumental in soliciting feedback early, routinely throughout the development process. The team acted as a task force for the development, providing a mechanism for continuous discussion and evaluation until the users' views were completely integrated into the tool, which would only increase the probability of use and effectiveness of the tool. The following sections describe in more detail the methodology applied to the development process.

REQUIREMENTS ANALYSIS

Upon review of relevant PPMOF decision tools discussed in the Background section, the proposed tool was “requirements-driven” to ensure its use and effectiveness in the user’s decision-making process. The users of the tool are defined as decision-makers in various organizations of the construction industry who are charged with evaluating the feasibility of PPMOF on a particular project. The potential users are represented in part by the team members. Since the tool should be designed to be used by these decision-makers, their involvement from the outset played a major role in defining the user requirements.

Specifically, the tool should provide a convenient means for the user to (1) weigh decision factors separately, (2) combine scores on factor categories according to his or her relative importance weights, and (3) obtain information on what factors could drive or impede the use of PPMOF on the project under consideration, rather than a decision or recommendation being given. In a sense this last requirement presented a crude way of addressing (but not analyzing) risks as well. The tool must also consider a variety of attributes of the users – such as style, acceptance, and preferences – and fit into their organizations. Care should be taken not to change drastically the present decision-making process and procedures (discussed in Background) with which the decision-makers are familiar.

The feasibility of the proposed tool was also studied in several dimensions: economic, technical, operational, and time factor. Since the decision to build the tool should be based on the value of facilitating the decision-making process, the tool aims at effectiveness rather than efficiency – it seemed that the tool could be developed from the existing resources in the team. Technically, the tool could be used without the problem of a lack of “organization readiness” (in which the organization lacks the time, expertise, or personnel required to

implement the tool), since the tool would be developed while considering its fit into organizations in which the user and the tool will operate (Bidgoli 1989). In addition, organizations' response to and general feelings toward the tool are expected to be affirmative since the tool can be used at the discretion of the users. From the time factor viewpoint, the development of the tool was considered feasible, too.

ANALYTICAL METHOD & SOFTWARE SELECTION

In view of the user requirements and needs analyzed, the weighted factor method was considered most suitable for evaluation of the feasibility of PPMOF. It is because the concept of the relative importance weights is central to the current decision-making paradigm in the PPMOF domain in which high scores on some factor categories are combined with low scores on others. The proposed tool should also allow the users to come up with their own relative importance weights. It might be disturbing to and difficult for the users, for the method emphasizes the subjective process they go through when evaluating the applicability of PPMOF. However, the relative importance weights represent personal judgments that should be made by themselves – the decision-makers, based on specific project characteristics.

This analytical method is one that has been applied to MODEX's feasibility analyses, yet with predetermined relative weights on factor categories. Concerning MODEX, Cigolini argued that the score of qualitative questions depends on the person answering, which prevents most construction managers from considering it a reliable tool (Cigolini 2002). However, his argument is tangential to the feasibility analyses of MODEX. As discussed in the Background, earlier decision-making on the use of PPMOF (like feasibility analysis) is essentially based on subjective evaluation by experienced personnel. The timing and nature of the earlier decision on applicability of PPMOF prescribes subjective

judgments. Unlike the tactical level decision involving cost comparison, this subjective assessment cannot be replaced with any mechanical procedures. The effectiveness of subjective evaluation at the strategic level establishes legitimacy of the weighted factor method for the proposed tool.

To embody the selected analytical method and user interface into the preliminary decision framework, a spreadsheet program sufficed for generating the tool. The analytical method selected is not computationally rigorous and does not require a data base for operation. It can be handled most efficiently in a spreadsheet format. Besides, the decision framework is such that it can be represented and manipulated more easily in a spreadsheet format. The choice of the team was Microsoft® Excel, one of the most familiar to immediate users of the tool (and probably, to the potential users in the industry), that provides capabilities to develop a customized application by using the relatively easy to learn programming language, Visual Basic for Applications (VBA). Working directly with a variety of hierarchical Excel objects, VBA can make the user interface flexible, simple, easy to use, responsive, and self-explanatory (Albright 2001).

PROTOTYPE DESIGN

The team communicated their views regarding the tool and defined the user needs more precisely, to have potential users' views integrated into the tool throughout development. This was made possible by prototyping, essentially an iterative process involving test, evaluation, and subsequent refinement (of the user interface, the scoring system of the analytical method, and even the decision framework). The prototype evolved into the final tool as existing features were upgraded and new features are added. Providing a mechanism for soliciting users' feedback routinely throughout development, the team members' active and

constructive involvement as a task force in the iterative process cannot be emphasized enough.

BETA TESTING AND VALIDATION

This step focused on formal evaluation of the prototype tool by prospective users. The beta testing was intended to determine: (1) whether the users generally like the tool, (2) what they consider to be its strengths and weaknesses, and (3) what changes they would suggest for improving it. Thus the beta testing represents a validation method assessing whether the tool actually improves the decision-maker's performance. Of primary concern was the usefulness and effectiveness of the tool to the decision-making process for PPMOF. The beta testing was however not concerned with "verification" issues – such as predicative accuracy, functional completeness, and logical consistency of the analytical method and the decision framework – which are subjects of what Adelman called a technical evaluation (Adelman 1992). In contrast, evaluation of the "technology-driven" MODEX and Neuro-MODEX was performed in other research heavily weighing the technical aspects (Murtaza et al. 1993, 1994). The procedures and results of beta testing are presented in greater detail in Chapter 5.

FINAL CONSTRUCTION OF THE TOOL & DOCUMENTATION

Suggestions for improvements to the prototype, conveyed by the beta testing, were incorporated into the final construction of the tool as the team discussed and found appropriate. Meanwhile, the guidelines to implementing the tool were also documented in the Implementation Resource (CII 2002) accompanied by the final version of the tool. Several significant improvements are reported in the Modifications section of Chapter 5.

The last step, evaluation or post-implementation audits, may be valuable to the development process, although beyond the scope of this research. By

evaluation, the team means a process that is much more comprehensive than the beta testing and involves systematic application of “explicit and appropriate” methods (Adelman 1992). The results of the evaluation, if performed at all, should be fed back into the development process.

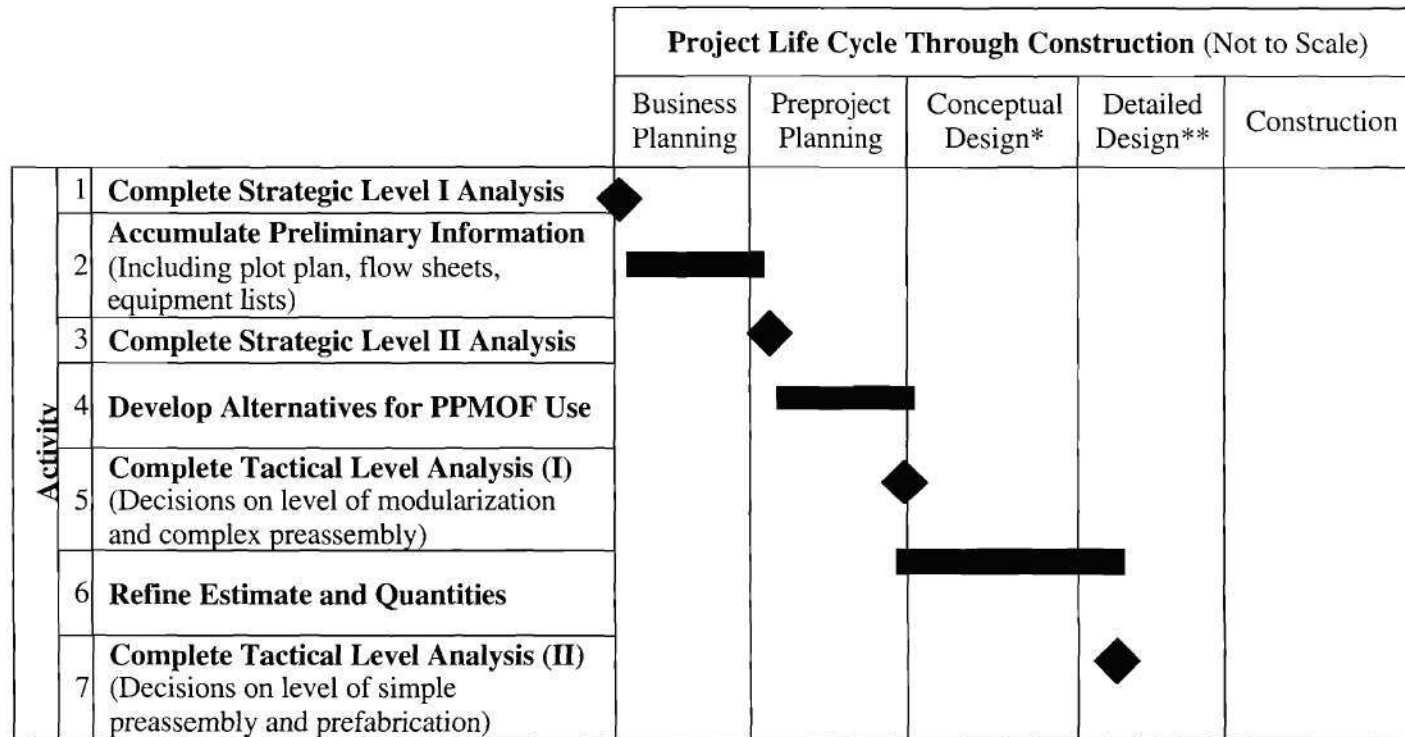
Chapter 4: Description of the Decision Tool

OVERVIEW

The preliminary decision-making framework was intended to help recognize the issues to consider in making early decisions on modularization, and later decisions on preassembly, prefabrication, and offsite construction (Fagerlund 2001). Since the overall decision-making process involves a spectrum of potential implementation choices rather than an “all or nothing” decision (Fagerlund 2001), the use of the decision framework should allow for variable timing of decision-making. For timing PPMOF decisions, see the roadmap in Figure 4.1 that the research team has developed to identify recommended points in the project life cycle.

Based on the preliminary research results, the tool was developed through the process described in the Methodology section. It aims at facilitating a systematic thought process by supporting the conceptual framework for decision making. Although subjective in nature, the tool was designed to assist in making good, judgment-based decisions at the strategic level during preproject planning. The tool can help identify the drivers and impediments to PPMOF that managers need to address in a project execution plan.

The tool can also be used to foster project team education and alignment through open communications. There are many perceptions at the start of a project, and work experiences and talents are varied and mixed. For instance, a project engineer will have one perception when thinking about a factor influencing PPMOF, and a construction manager will have another. A true view of a total project can be developed by having several persons with various talents and experiences evaluate the applicability of PPMOF independently using the tool.



* At start of conceptual design: estimate approximately $\pm 30\%$, team has plot plan, equipment list, flow sheets

** At start of detailed design: estimate approximately $\pm 10\%$, quantities determined

Figure 4.1: Roadmap for PPMOF Decisions (adapted from Fagerlund 2002)

The analysis of PPMOF can vary based on the nature of the project, the participants, and the options available. Analysis elements such as timing, information requirements, levels of involvement and communication requirements all factor into the decision-making process. The decision-making framework was divided into three levels (Fagerlund 2002). The first and second levels are designed to provide subjective insight into the applicability of PPMOF based on primary drivers and impediments. They are strategic in nature. These levels are directed at global project goals and objectives. The Strategic Level I analysis, comparable to the initial feasibility analysis of MODEX, is designed to serve as a business planning screening tool to identify major drivers and impediments to PPMOF. The Strategic Level II analysis, comparable to the detailed feasibility analysis of MODEX, is a pre-planning screening tool to further identify opportunities for PPMOF beyond the Level I. It results in a much more thorough assessment.

Strategic Level I analysis can be conducted using the form presented in Figure 4.3. Strategic Level II analysis is implemented in the form of a spreadsheet program which is contained in a disk that accompanies the Implementation Resource (CII 2002). Its introductory worksheet is presented in Figure 4.2.

The final step in the decision process is a tactical level analysis. The final tactical analysis is focused on a cost comparison to determine feasibility and scope of PPMOF during quantity-level estimating. It may also involve risk analysis incorporating such elements as skilled labor availability. The tactical tool would be used for less complex PPMOF such as simple preassemblies and prefabricated components.


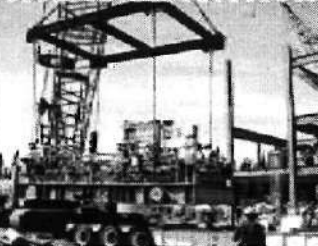
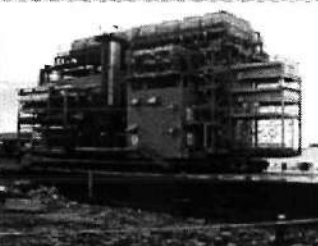
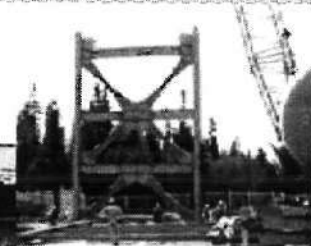
CII Strategic Decision Tool for PPMOF (Prefabrication, Preassembly, Modularization, and Off-site Fabrication)			
This is the Welcome Page			
			
Prefabrication	Preassembly	Modularization	Off-site Fabrication
Please fill out the following data for your evaluation.			
Project Name:	<input type="text"/>	Name of Evaluator:	<input type="text"/>
Project Location:	<input type="text"/>	Date:	<input type="text"/>
Project Owner:	<input type="text"/>	Evaluation Date:	June 19, 2002
Please click on "Strategic Decision Level II" to start your evaluation.			Strategic Decision Level II

Figure 4.2: PPMOF Strategic Decision Tool Introductory Worksheet

STRATEGIC LEVEL I ANALYSIS

The purpose of Strategic Level I analysis is to provoke thought and provide insight into PPMOF potential very early in the project at the highest level of planning. It is designed to assist pre-project planners in identifying opportunities early in the business planning phase based on major drivers and impediments to the use of PPMOF. This level contains a concise list of questions, presented in Figure 4.3, concerning these major drivers and impediments to initially evaluate the feasibility of using PPMOF.

After completing the six questions in the framework, a project team will have identified potential drivers for PPMOF use to be considered later in the project. The framework provokes thought and discussion early in the project, preparing the project team for the early decisions required for some types of PPMOF. Strong indicators at Level I lead the team to Strategic Level II analysis, which is designed to be used later in the planning process when more information is known about the project. Further analysis and investigation using the Strategic Level II and Tactical Frameworks is necessary to calculate impact on project objectives in a more comprehensive manner.

The Level I framework shown in Figure 4.3 simply requires a “yes,” “maybe,” or “no” answer to a series of six questions. The first column represents the section or category of the question. The second column presents the question related to the section, as well as how PPMOF influences the section. The scoring is handled in the final columns. An answer of “yes” means the factor strongly drives adoption of PPMOF. An answer of “maybe” means the factor may drive PPMOF. An answer of “no” indicates the factor of concern does not drive PPMOF. A majority of “yes” or “maybe” answers indicates that PPMOF may be advantageous to the project, and further analysis at an early planning stage is merited. A majority of “maybe” and “no” answers indicates that PPMOF is

probably not feasible. However, less comprehensive forms of PPMOF may still be feasible at a later phase in the project (i.e., modularization may not be feasible, but prefabrication may be feasible for later phases of the project). The questions should be answered based on knowledge of the project under consideration. Results of the analysis may be saved for later use, to be combined with the results of the other two PPMOF levels of analysis for ongoing decisions regarding PPMOF.

Decision Support for Prefabrication, Preassembly, Modularization, and Off-site Fabrication				
Strategic Level I Evaluation		Evaluation Date:		
Project Name:		Evaluator:		
Answer questions based on knowledge of the project under consideration. Follow the interpretation and save the results for later use, as they can be combined with the results of later evaluations for the final decisions regarding PPMOF.				
Section	Question	Impact on PPMOF		
Schedule	Are there significant constraints or requirements for the project schedule? PPMOF may help to meet schedule constraints such as outage duration and time to market or decision needs.	<input type="checkbox"/> Yes	<input type="checkbox"/> Maybe	<input type="checkbox"/> No
Labor	Is there a lack of good local labor available in the project area? PPMOF may help by moving work to areas with adequate labor.	<input type="checkbox"/> Yes	<input type="checkbox"/> Maybe	<input type="checkbox"/> No
Safety	Is there an opportunity to decrease safety risks by using PPMOF? PPMOF may be able to relocate work to less hazardous environments such as ground level or controlled climates.	<input type="checkbox"/> Yes	<input type="checkbox"/> Maybe	<input type="checkbox"/> No
Environmental, Legal and Regulatory	Are there significant environmental, legal and /or regulatory considerations that may constrain the project? PPMOF may help to alleviate constraints by allowing parallel work while such issues are handled.	<input type="checkbox"/> Yes	<input type="checkbox"/> Maybe	<input type="checkbox"/> No
Site Attributes	Are there significant site attributes such as extreme weather or lack of infrastructure that may impact project performance? PPMOF can potentially relocate work to more favorable conditions.	<input type="checkbox"/> Yes	<input type="checkbox"/> Maybe	<input type="checkbox"/> No
Site Access	Do available routes and lifting paths allow using modules with the dimensions set by truck, rail, or barge shipment? Using the largest possible modules increases the benefits of PPMOF.	<input type="checkbox"/> Yes	<input type="checkbox"/> Maybe	<input type="checkbox"/> No

Figure 4.3: Strategic Level I Analysis

STRATEGIC LEVEL II ANALYSIS

The purpose of Strategic Level II analysis is to delve into the areas highlighted in Level I to further determine PPMOF feasibility as project definition increases. Level II broadens and deepens the analysis based on Level I categories and is designed for use during the pre-project planning process. Level II requires slightly more knowledge about the project so it is carried out later in the pre-project planning and conceptual design phases. This knowledge may include site location, plot plan, processes, as well as general characteristics regarding infrastructure, required labor, permitting, and legal issues. The framework is separated into ten sections corresponding to ten categories, listed in Table 4.1.

Table 4.1: Strategic Level II Analysis Categories

• Schedule	• Mechanical Systems
• Cost	• Project and Contract Types
• Labor	• Design
• Safety	• Transportation & Lifting Requirements
• Site Attributes	• Supplier Capability

The Strategic Level II analysis was designed primarily based on case studies of industrial projects. While many of the categories and the specific factors within each category are common to various types of projects, it should be noted that the user of the framework might want to add or subtract questions to tailor it towards other construction industry sectors. Like Level I analysis and Tactical analysis, Level II analysis is designed to provoke thought rather than provide a comprehensive list of all the factors influencing a project with regard to PPMOF.

Answering the questions in the Level II analysis tool helps the team begin to identify drivers and impediments to PPMOF, as well as their relative weights. Analyzing the drivers and impediments for the project considering the additional information obtained over the pre-project planning phase will allow the project team to develop several cases of varying levels of PPMOF. The Tactical level of analysis involves a cost comparison of these cases.

In the evaluation process for Strategic Level II analysis, users are guided through several steps as described in Figure 4.4. Users are first asked to assign weight factor values to each of ten categories. Each weight factor value represents the user's judgment of the relative importance of its corresponding category. The weight factor values can be any number between 0 and 5. A category given a zero weight factor value does not contribute to the final score even if users have completed detailed questions for the category.

CII Strategic Decision Tool for PPMOF
(Prefabrication, Preassembly, Modularization, and Off-site Fabrication)

This is the Home of Strategic Level II Evaluation

The purpose of Level II of the strategic decision tool is to evaluate in more detail ten categories of factors that may serve as drivers or impediments to the use of PPMOF for a particular project.

In this evaluation process, you will go through the following steps:

1. Assign weights to each of ten categories.
2. Evaluate detailed questions for each category.
3. Assess your final score based on raw scores of detailed questions and weighting for each category.
4. View Interpretation of Final Score and Reports of Extremes.
5. Optionally, save and print your evaluation results.

Upon completion of all of the questions, specific drivers and barriers to PPMOF will have been identified as well as their relative weights.

Please click on the 'Start Evaluation' button to proceed. [Start Evaluation](#) [Welcome Page](#)

Figure 4.4: Evaluation Process for Strategic Level II Analysis

Figure 4.5 illustrates example weight factor values in the Summary sheet. As users proceed to assign weight factor values to each category, weight factor percents are updated and quantify the user's relative importance of categories by dividing the weight factor value of its corresponding category by sum of the weight factor values assigned. Thus, the weight factor percents will always sum to 100%.

CII Strategic Decision Tool for PPMOF (Prefabrication, Preassembly, Modularization, and Off-site Fabrication)				
Summary of Strategic Level II Evaluation				
Project Name: Fill out on Welcome page		Data Date: Fill out on Welcome page		
Evaluator: Fill out on Welcome page		Evaluation Date: June 19, 2002		
First, please assign numbers between 0 and 5 to the weight factor for each of the ten categories below.		What's the weight factor?	Weight factor percentage?	
Category	Average Raw Score A	Weight Factor (0 to 5) B	Weight Factor Percent $C=B/\Sigma B$	Weighted Score $D=A*C$
1. Schedule		5	20%	0.00
2. Cost		4	16%	0.00
3. Labor		3	12%	0.00
4. Safety		2	8%	0.00
5. Site attributes		3	12%	0.00
6. Mechanical system		1	4%	0.00
7. Project and contract type		0	0%	0.00
8. Design		2	8%	0.00
9. Transportation and Lifting requirements		3	12%	0.00
10. Supplier capability		2	8%	0.00
Second, please click on the "Detailed Questions" and assess raw scores for each category.		Detailed Questions	100%	Final Score ΣD

Figure 4.5: Example of Assigning Weight Factor Values to Ten Categories

Although users can modify or assign weight factors after completing the detailed questions, the research project team recommends completing this before proceeding with the detailed questions. Weighted Scores and the Final Score in the last column of the Summary are continuously recalculated as the user completes the Detailed Questions in each of the ten categories. When users have assigned weight factor values, they click on the button captioned “Detailed Questions” and are guided to the next step to answer ten categories of detailed questions, starting with Schedule category.

Figure 4.6 illustrates the layout of a Detailed Questions section of the Level II spreadsheet tool. Each section of the analysis focuses on a category of factors identified at the top of the table for that section. Column 1 assigns a unique number to each question and gives a brief title. Column 2 describes the impact that specific forms of PPMOF may have on the project. Examples of the impact can be viewed by moving the mouse cursor over the triangle at the upper right corner in the Description cell.

The next group of six columns allows the user to assess the impact of PPMOF more specifically, using a scale ranging from -5 to +5. A positive score indicates that project conditions favor PPMOF regarding the specific factor; a negative score indicates that project conditions favor field work regarding the specific factor. If a factor is not applicable to a specific project under evaluation, N/A should be assigned. If users do not provide any response, either a score (-5 to +5) or N/A, for a detailed question, the question is considered unanswered. Only when all the questions in a category are answered, the raw scores for each factor are averaged across the category to provide a category raw score. Otherwise, the Average Raw Score for a category remains “Incomplete” as shown in Figure 4.6. The average category raw score is obtained by dividing the sum of factor scores by the number of factors given in the category and then transferred to Column 2 Average Raw Score of the Summary sheet (Figures 4.5 or 4.7).





Detailed Questions of Strategic Level II Evaluation									
1. Schedule		To what extent could the following schedule related issues be desirable for traditional field erection (negative value) or desirable for PPVDF (positive value) for the project under consideration?						Home  	
Factor	Description	N/A	Desirable for Field Erection		Neutral		Desirable for PPVDF		
			-3	-2	0	+2	+3		
1.1 Shortener schedules	Pework may compress the schedule through pre-e activities and higher end productivity rates.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	
1.2 Planned shutdowns, outages, or turnarounds	Maximizing assembly and verification prior to construction has the potential to reduce shutdown time.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	
1.3 Late business decisions	Pework has the potential to compress the installation schedule by allowing higher shop productivity and multiple fabrication steps allowing postponement of final business decisions related to bringing a product to market.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	
1.9 Rewards for early project completion	Schedule compression and/or reduction in schedule variance through prework may provide opportunities for incentives if available.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	
1.10 Requirements to get product to market rapidly	Pework may be able to reduce time to market through improved productivity rates in the shop and by desequencing activities. This may allow products to reach the market sooner.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	
Please click on the right arrow and move to the next category of detailed questions.			 		Final Score	Average Raw Score	Incomplete		

Figure 4.6: Example of Detailed Questions of Strategic Level II Analysis

This average category raw score is not affected by any factor in a category given N/A or a zero score. However, the difference between N/A and a zero score is important. While a factor given N/A will never be considered to be a driver or impediment to PPMOF for the Reports of Extremes, one given a zero score may be shown in the Reports of Extremes, described later. See Appendix A for the detailed questions in each of the ten categories. Once users complete answering the last category of detailed questions, they are guided back to the Summary sheet (Figure 4.7).

CII Strategic Decision Tool for PPMOF (Prefabrication, Preassembly, Modularization, and Off-site Fabrication)				
Summary of Strategic Level II Evaluation				
Project Name: Fill out on Welcome page		Data Date: Fill out on Welcome page		
Evaluator: Fill out on Welcome page		Evaluation Date: June 19, 2002		
First, please assign numbers between 0 and 5 to the weight factor for each of the ten categories below.				What's the weight factor?
				Weight factor percentage?
Category	Average Raw Score A	Weight Factor (0 to 5) B	Weight Factor Percent C=B/5B	Weighted Score D=A*C
1. Schedule	1.40	5	20%	0.28
2. Cost	0.40	4	16%	0.06
3. Labor	-0.40	3	12%	-0.05
4. Safety	1.00	2	8%	0.08
5. Site attributes	0.13	3	12%	0.02
6. Mechanical system	0.63	1	4%	0.03
7. Project and contract type	2.25	0	0%	0.00
8. Design	1.29	2	8%	0.10
9. Transportation and Lifting requirements	0.40	3	12%	0.05
10. Supplier capability	-1.40	2	8%	-0.11
Second, please click on the "Detailed Questions" and assess average raw scores for each category.		Detailed Questions	100%	0.45
Finally, once weight factors and raw scores are found, please click on the "Final Score Interpretation" and "Reports of Extremes" buttons.			Final Score Interpretation	Reports of Extremes

Figure 4.7: Example of Strategic Level II Evaluation Summary

Here users can assess the final score based on their average category raw scores and assigned weight factor values. They are also given the opportunity to modify or refine the assigned weight factor values. Column 3 of the Summary sheet is the relative weight that users have assigned to each category, and Column 5 is the weighted score of each category. This is calculated by multiplying the average category raw score by the weight the user selects. The Interpretation of the Final Score shown below in Figure 4.8 can be viewed by clicking on the “Final Score Interpretation” button at the bottom of the Summary sheet.

CII Strategic Decision Tool for PPMOF
(Prefabrication, Preassembly, Modularization, and Off-site Fabrication)

Interpretation of the Final Score for Strategic Level II Evaluation

This is your final project score, and it can range between -5 to 5. A positive value indicates that PPMOF is a desirable strategy for your project. Lower values indicate less support; higher values indicate more support.

A negative value indicates that PPMOF is an undesirable strategy for your project. Values close to 0 indicate no preference overall but leave open the possibility that PPMOF would be applicable to areas of the project.

- The Reports of Extremes identify key drivers and impediments.
- Focus on the individual items, and not only on the final numerical total results.
- The results should be interpreted as a consensus document for the project team.
- The Raw scores offer good qualitative guidance regarding the applicability of PPMOF.
- The Final score can be used to create historical data, to relate to project success.

Any final decisions need to be supported by a thorough cost/benefit analysis, or a tactical analysis as recommended in the Implementation Resource.

Please click on the "Reports of Extremes" to view your key drivers and impediments to PPMOF for the project under consideration.

Reports of
Extremes

Final Score

Figure 4.8: Interpretation of the Final Score for Strategic Level II Analysis

Completing all of the detailed questions as well as their relative weights, specific drivers and barriers to PPMOF for the project under consideration results in identifying the Factors Most Strongly Supporting PPMOF and Factors Most Strongly Against PPMOF, as shown in Figures 4.9 and 4.10, respectively.

CII Strategic Decision Tool for PPMOF (Prefabrication, Preassembly, Modularization, and Off-site Fabrication)					
Reports of Extremes for Strategic Level II Evaluation					
Project Name:		Fill out on Welcome page		Data Date:	
Evaluator:		Fill out on Welcome page		Evaluation Date: June 19, 2002	
Factors Most Strongly Supporting PPMOF					
Rank	Raw Score	Weighted Score	Factor	Category	Question No.
1	5	1.00	Shortened schedules	Schedule	1
1	5	1.00	Timing of environmental or other project permitting	Schedule	5
2	5	0.60	Local, regional, or national labor availability	Labor	3
3	5	0.40	Reductions in insurance costs	Safety	6
3	5	0.40	Requirement for early "freezing" of design	Design	2
3	2	0.40	Late business decisions	Schedule	3
3	2	0.40	Early startup benefits	Schedule	4
3	2	0.40	Rewards for early project completion	Schedule	9
4	2	0.32	Requirements to meet new regulatory or other imposed requirements	Cost	3
4	2	0.32	Future reuse value	Cost	4
To save and print your evaluation results, please go to the Final Score (Summary) sheet and press the "Save" and "Print" buttons.				Final Score	Final Score Interpretation

Figure 4.9: Example Reports of Extremes – Factors Most Strongly Supporting PPMOF

CII Strategic Decision Tool for PPMOF (Prefabrication, Preassembly, Modularization, and Off-site Fabrication)					
Reports of Extremes for Strategic Level II Evaluation					
Project Name:		Fill out on Welcome page		Data Date:	Fill out on Welcome page
Evaluator:		Fill out on Welcome page		Evaluation Date:	June 19, 2002
Factors Most Strongly Against PPMOF					
Rank	Raw Score	Weighted Score	Factor	Category	Question No.
1	-5	-0.60	Local/Regional political considerations	Labor	9
1	-5	-0.60	Environmental restrictions	Site attributes	3
2	-5	-0.40	Supplier's availability of on-site representation	Supplier capability	5
2	-5	-0.40	Increased risk from high elevations, confined spaces, known toxic atmospheres, etc.	Safety	4
2	-2	-0.40	Equipment or materials with long lead-time	Schedule	7
3	-2	-0.32	Overall project cash flows	Cost	2
4	-2	-0.24	Labor agreements or jurisdictional issues	Labor	6
4	-2	-0.24	Multiple shifts of construction workers	Labor	10
4	-2	-0.24	Political issues	Site attributes	2
4	-2	-0.24	Risks of loss during transportation	Transportation & Lifting requirements	5
To save and print your evaluation results, please go to the Final Score (Summary) sheet and press the "Save" and "Print" buttons.				Final Score	Final Score Interpretation

Figure 4.10: Example Reports of Extremes – Factors Most Strongly Against PPMOF

These Reports of Extremes can be viewed by clicking on the “Reports of Extremes” button at the bottom of the Summary sheet (Figure 4.7) or the Final Score Interpretation sheet (Figure 4.8). Uncompleted detailed questions or weight factor values will however restrict access to the Reports of Extremes. The Reports give two top 10 lists of the factors most strongly supporting PPMOF (drivers) and of the factors most strongly against PPMOF (impediments) for the project under consideration.

Column 2 of the Reports of Extremes shows the raw scores for each factor that users have assigned when answering the detailed questions in each category. Column 3 gives weighted scores for each extreme factor that are calculated by multiplying the factor raw score by its category weight factor percent. For instance, if a user has assigned weight factor values in the Summary sheet so that Schedule category accounts for 20% of all weight factor values (i.e., its weight factor percent is 20%) and assigns +5 (Pro PPMOF) to a factor in the Schedule category, the factor’s weighted score is $5 \times 20\%$ or 1.00. As discussed earlier, any factor given N/A will not be shown in the Reports of Extremes while a factor given a zero score could be a candidate for a driver or impediment to PPMOF for the project under user’s consideration. This weighted score is used as the most important criterion in ranking the extremes factors.

Users can save their results of Strategic Level II Analysis as a different file and print the worksheets including the Summary, Reports of Extremes, and Detailed Questions, by clicking on the “Save” and “Print” buttons at the bottom right corner in the Summary sheet (Figure 4.7). The “Save” button leads users to the Excel’s built-in Save As dialog Box in which they are prompted to provide a different file name (since the spreadsheet tool is opened as read-only so may not be saved as the same name). The “Print” button guides users to a customized dialog box in which they can select pages to print (Figure 4.11). Pressing the OK button shows the users which pages they have selected for printing (Figure 4.12).

They may now click on the Yes button to proceed with the Excel's built-in Print dialog box to make further options, or press No to make changes to selected pages.

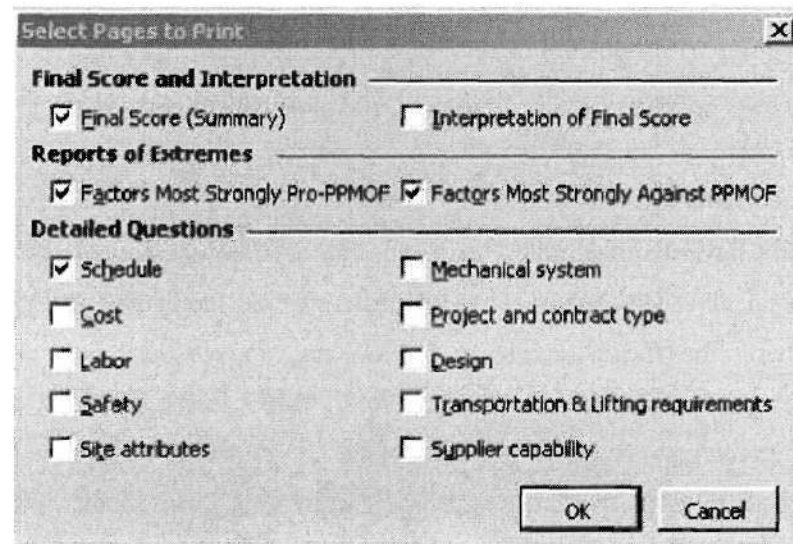


Figure 4.11: Example of Selecting Pages to Print

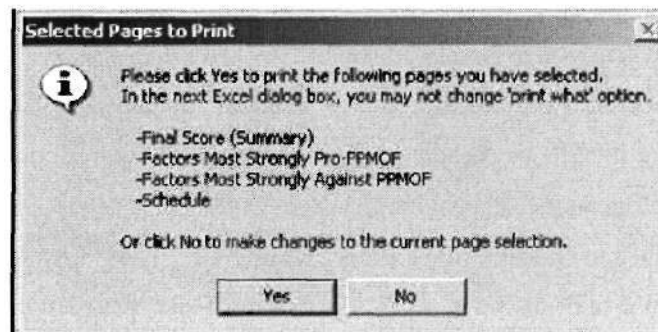


Figure 4.12: Example Selected Pages to Print

TACTICAL LEVEL ANALYSIS

The purpose of the tactical analysis is to provide a cost comparison of different PPMOF strategies on a project. The suggested timing of the analysis is during the conceptual design phase and in some cases again later in the beginning of detailed design, as shown in the Roadmap (Figure 4.1). While the strategic level analyses focused on global project goals and objectives, tactical analysis focuses on a more detailed level of cost comparison.

Even though a high level of detail may not be required for decisions regarding modularization and complex preassembly, the preliminary research showed that many types of simple preassembly and prefabrication decisions were often based on detailed cost, labor and schedule comparisons with conventional options (Fagerlund 2002). Some projects or management structures may call for more than one cost analysis based on varying levels of funding requirements or information availability.

Prior to completing the Tactical Framework, the project team will have completed the Strategic Level II Analysis, obtained project information (including plot plan, equipment list, transportation constraints and flow sheets), and developed several cases using varying levels of PPMOF. Regardless of the level or type of PPMOF, most cases call for some form of cost comparisons.

Typical cases could include a completely stick built option; a project with maximized modularization; or a project with some preassemblies and prefabrication. Figure 4.13 shows a sample structure for compiling PPMOF alternatives. Once these alternatives have been identified, and the proposed levels and scopes of PPMOF have been determined, a detailed tactical analysis can be executed to determine cost effectiveness between the stick built and PPMOF options.

Case #1: 40% PPMOF				
PPMOF Type	Length	Width	Height	Weight
<u>Modules</u> <i>e.g. Reactor in Area 1</i>				
<u>Preassemblies</u> <i>e.g. Compressors in Area 2,3</i>				
<u>Prefabrication</u> <i>e.g. Pipe Spools in Area 3,4,5</i>				

Figure 4.13: Example of Case Option for Tactical Analysis

The tactical analysis should focus on determining cost, schedule and labor impact. Further development of these cases begins with the company work breakdown structure (WBS). Prior to determining the cost impact, a method of estimation must be selected. The estimator may choose to utilize cost adjustment factors or bottom up estimation strategies. Sections of the project may be considered from a unit cost or an assembly standpoint. The cost adjustment factor applied to an assembly will provide a high level estimate for the cost impact of PPMOF.

For a more detailed analysis, a bottom up strategy could be applied to items at the unit cost level. The total cost impact is based on the combination of additional costs and cost savings resulting from the use of PPMOF for each case identified. Figure 4.14 shows the approach for cost comparisons between alternatives. For another approach to the tactical level analysis of modularization alternatives, a recent article (Cigolini 2002) may be referred to.

Risk analysis with respect to labor impacts might involve labor resource profiles for each case analyzed. For a case where major PPMOF work is estimated, the on-site labor requirements and peak labor requirements would

likely be lower than a conventional project and thus would expose the project to less risk associated with local skilled labor shortages.

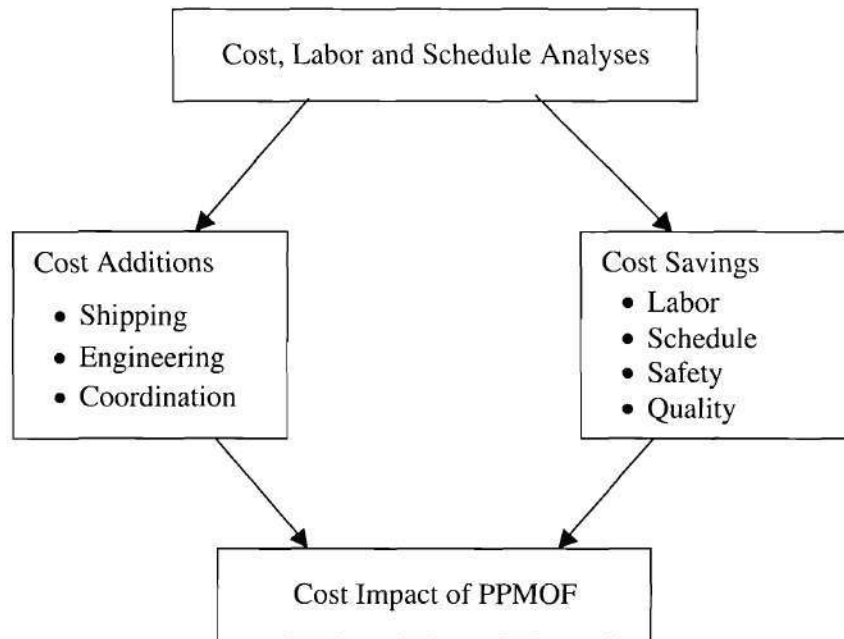


Figure 4.14: A Structure for Cost Comparisons among PPMOF Alternatives

Chapter 5: Validation Results and Modifications

OVERVIEW

Before the final construction of the tool described in the previous chapter, the prototype of the tool was developed through an iterative process and beta tested to determine: (1) whether the prospective users generally like the tool, (2) what they consider to be its strengths and weaknesses, and (3) what changes they would suggest for improving it. To this end the validation was performed by voluntary contributors solicited through the industry team member companies.

The beta test package included a cover letter explaining the intent of beta testing, a draft research summary providing some background on preliminary results of this research, draft guidelines explaining how to use the tool, and a survey questionnaire with a copy of the spreadsheet prototype tool. The projects considered for PPMOF at the beta testing were in stages varying from preproject planning to construction to completion. They all fall into a type of industrial facilities, with the estimated project cost ranging from \$20 MM to \$350 MM, and approximate total schedule duration from 15 to 32 months. Eight sets of a survey questionnaire were completed by project managers, construction managers, and an owner's process designer. They were completed either individually or as a team, and the contributors came from owner, construction management, project management companies, general contractor, and subcontractor/supplier.

VALIDATION RESULTS

The beta testing of the prototype tool validated its effectiveness in the decision-making process for PPMOF, as conveyed by the survey responses. Specific questions about the prototype tool covered its usefulness, ease of use, and helpfulness in the decision-making process and team alignment. All these short-

answer questions required the participant to respond on a cardinal scale from “strongly disagree” to “strongly agree.” In general, the respondents considered the tool to be effective, with its usefulness favored in most cases, the ease of use in fewer cases. The survey questionnaire also had an open-ended question that gave the participants an opportunity to recommend improvements to the prototype. They also took this opportunity to indicate what they perceived to be strengths of the prototyped tool. Specific comments included:

- “flexible in letting the user weigh the factor weights”
- “brings all of the factors associated with the decision on PPMOF into the evaluation; the series of questions raised some additional issues that had not been considered when first evaluating the applicability of PPMOF”
- “helps to highlight areas of concern for extra and early planning; it would give a team the items to emphasize in early planning for the modular project if the decision to modularize have already been made”
- “provided a tool for the project team to use to evaluate the execution strategy”
- “when completed as a team, input from all contributors would be solicited and considered”
- “examples added to the description of factors were very helpful to narrow the team’s focus as a team can have a different interpretation or reaction to each decision factor.”

Specific suggestions for improvement to the prototype tool were related to ease of use, the scoring system, semantics, etc., including:

- “add a complete button at the end to save and close the worksheet file”
- “provide a “Print All” option so each individual page does not have to be printed”

- “the selection of ‘N/A’ rather than zero has too big an impact on the scoring system; a little assistance with the definitions would help the consistency of scores across a team of people”
- “revisit some of the questions and change texts; there are a few questions/statements that are not clear, or repeated in several categories”
- “further explanations on category weight factors should be provided; fixed limits (i.e., some range of values) to apply them may be useful; it would be helpful to know how the weight factor percents are decided”
- “add explanation on what the final score means”
- “Strategic Level I analysis was not very useful and can cause confusion as it implies that the impacts to PPMOF at the Level I may be linked with those at Level II (the research team had tried to prevent this confusion by having the user go back to the home page and then optionally, start the Level II analysis, but respondents were still misled and wished a new button to go onto the next step, or the Level II analysis).”

MODIFICATIONS

The validation results were presented at a research team meeting. The research team decided to make every effort to incorporate the feedback of beta testing into the final construction of the tool. New save and print features were added. The scoring system was revamped in a way such that the selection of “N/A” or zero would not affect either the category or final scores, thereby the Reports of Extremes being not biased by the number of questions in each category regardless of how many questions in a given category are scored “N/A”. Also, further explanations on the category weight factors and weight factor percents were provided, a separate page was added to explain what the final score could mean, and the Strategic Level I analysis was taken out of the computerized tool but remains as part of the decision framework. Once again, the detailed questions

were reorganized, and wordings were carefully refined. Finally, the team worked on cosmetics of the tool to offer a consistent look and reference points across the evaluation process.

Chapter 6: Conclusions and Recommendations

CONCLUSIONS

Based on the key findings and conceptual framework of the preliminary research, this research was conducted to develop a computerized tool for use by various professionals in the construction industry to aid in evaluating the feasibility of PPMOF on an industrial project. The conclusions reached are summarized below:

- Decisions on the applicability of PPMOF are of a subjective nature that are typically made early in preproject planning. They are often based on in-house expertise which is elusive and difficult to capture in the form of rules or patterns. The preliminary research has shown that modularization and complex preassembly decisions are typically based on an experts' evaluation of broad factors at the strategic planning level, while other levels of PPMOF are decided based on unit cost considerations later at the tactical level.
- The industry represented by the research team has had a need for a computerized tool to facilitate their evaluation of the applicability of PPMOF at the strategic level, as part of the overall decision-making process of PPMOF. The preliminary research has found that the overall decision-making process involves a spectrum of potential implementation choices rather than an "all or nothing" decision.
- The development of the proposed tool was "requirements-driven" instead of "technology-driven," conducive to the current decision-making paradigm of the industry for evaluating the feasibility of PPMOF.
- The beta testing of the prototype tool developed through an iterative process validated its usefulness, ease of use, and effectiveness in the

decision-making process for PPMOF. Prospective users in the industry found that the tool would bring all the factors associated with the decision on PPMOF into the evaluation, would help to highlight the items to emphasize in the execution strategy, and could be used to align a project team.

RECOMMENDATIONS

Several Recommendations can be made that would enhance the effectiveness and capabilities of the tool developed in this research:





- Further research should be performed to evaluate the effectiveness of the tool with the systematic application of explicit and appropriate methods. The evaluation should be concerned with value added by facilitating and improving the decision-making process and interpersonal communication, rather than based on the monetary benefits generated by the tool. The results of such an evaluation could then be fed back into the development process (which never really ends).
- The technical “verification” of the developed tool should be also pursued to determine its predicative accuracy, functional completeness, and logical consistency when a significant amount of data becomes available. The data to be collected should include category factor weights or weight factor percents, the final score, the level of project definition at the time of PPMOF decision-making, and project performance measures. Then the verification procedure is to determine if there is a significant level of correlation or causal relationship between a weighted decision factor category and project performance measures. For instance, if decision-makers assigned to the schedule category a relatively high weight and PPMOF was applied to a schedule-driven project, then the project may have been completed early, partly due to the use of PPMOF. However, it

should be noted that such a correlation analysis can be biased since it concerns only bivariate relationships and is unable to take into account other variables (e.g., the level of project definition at the decision timing) which may have a significant effect on the relationships. Potential benefits from use of PPMOF can be offset by implications from its use, and without the proper level of project definition, impediments to implementing PPMOF cannot be addressed. As such, multiple regression or more sophisticated models should be employed for the verification purpose. Also sensitivity analyses may be merited.





- The decision framework and the tool should be adapted to other areas of the construction industry (e.g., building construction) that can benefit from the use of PPMOF. The development process of such framework and tool may merit methodology similar to that adopted in this research.
- The tactical level analysis of the decision framework should be further developed and then converted into a software tool to help: (1) develop specific options applicable to implementing PPMOF decisions, (2) determine cost, schedule and labor impact, and (3) assess risk associated with each option. Substantial efforts should be directed to requirements analysis and selection of appropriate analytical methods. A design approach should emphasize iteration, evaluation, and subsequent refinement.
- An educational module to aid the industry in implementing PPMOF should be developed and incorporated into other relevant modules, such as project constructability and preproject planning.

Appendix A: Detailed Questions for Strategic Level II Analysis

CATEGORY 1 – SCHEDULE

CII Strategic Decision Tool for PPMOF (Prefabrication, Preassembly, Modularization, and Off-site Fabrication)							
Detailed Questions of Strategic Level II Evaluation							
1. Schedule		To what extent could the following schedule related issues be desirable for traditional field erection (negative value) or desirable for PPMOF (positive value) for the project under consideration?				Home  	
Factor	Description	N/A	Pro Field Erect	Neutral	Pro PPMOF		
			-5	-2	0	+2	+5
1.1 Shortened schedules	Prework may compress the schedule through parallel activities and higher shop productivity rates.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
1.2 Planned shutdowns, outages, or turnarounds	Maximizing assembly and verification prior to construction has the potential to reduce shutdown time.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
1.3 Late business decisions	Prework has the potential to compress the installation schedule by utilizing higher shop productivity and multiple fabrication sites, allowing postponement of final business decisions related to bringing a product to market.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
1.4 Early startup benefits	Schedule compression resulting from multiple work sites and increased productivity at remote sites along with equipment performance verification prior to installation can result in a shorter startup learning curve.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
1.5 Timing of environmental or other project permitting	Prework may allow work to begin offsite while site permits are being processed. (caution must be exercised due to the possibility of the permit request being denied)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
1.6 Time limitations related to shipping and transportation	Project locations may dictate or limit the ability to ship, receive or install elements. Prework shipments may require timing with shipping or transportation windows and may be restricted if the shipping window is missed.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
1.7 Equipment or materials with long lead-time	Long lead items may dictate schedule regardless of level of prework. Such items may also control the level and scope of prework.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
1.8 Risks associated with schedule penalties	By reducing schedule risks associated with weather or labor conditions, prework may limit the risk of schedule penalties.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
1.9 Rewards for early project completion	Schedule compression and/or reduction in schedule variance through prework may provide opportunities for incentives if available.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
1.10 Requirements to get product to market rapidly	Prework may be able to reduce time to market through improved productivity rates in the shop and by desequencing activities. This may allow products to reach the market sooner.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Please click on the right arrow and move to the next category of detailed questions.		 	Final Score	Average Row Score	Incomplete		

CATEGORY 2 – COST

CII Strategic Decision Tool for PPMOF (Prefabrication, Preassembly, Modularization, and Off-site Fabrication)							
Detailed Questions of Strategic Level II Evaluation							
2. Cost		To what extent could the following cost related issues be desirable for traditional field erection (negative value) or desirable for PPMOF (positive value) for the project under consideration?				Home  	
Factor	Description	N/A	Pro Field Erection -5	-2	Neutral 0	+2	Pro PPMOF +5
2.1 Overall project cost control	Characteristics of prework may provide tighter cost control (the ability to more accurately forecast and meet cost projections by limiting variability due to weather, labor, etc.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2.2 Overall project cash flows	Prework has the potential to provide more options for cash flow since work can be completed sooner or delayed without affecting targets.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2.3 Requirements to meet new regulatory or other imposed requirements	Compressing the schedule through the use of pre-work could allow the facility to attain compliance with the regulations by the mandated deadline.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2.4 Future reuse value	Prework aspects of a project can be designed for salvage or reuse.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2.5 Specific local economic factors	By relocating work offsite through prework, adverse local economic factors can potentially be avoided.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Please click on the right arrow and move to the next category of detailed questions.				Final Score	Average Row Score	Incomplete	

CATEGORY 3 – LABOR

CII Strategic Decision Tool for PPMOF (Prefabrication, Preassembly, Modularization, and Off-site Fabrication)							
Detailed Questions of Strategic Level II Evaluation							
3. Labor		To what extent could the following labor related issues be desirable for traditional field erection (negative value) or desirable for PPMOF (positive value) for the project under consideration?					
Factor	Description	N/A	Pro Field Erection -5	-2	Neutral 0	+2	Pro PPMOF +5
3.1 Labor productivity	Prework labor productivity rates are potentially higher due to factors such as factory conditions. There are many cases where shop wage rates for pre-work are significantly lower due to multiple variables.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3.2 Overall or peak labor density requirements (quantity of workers)	Prework can relocate work to an area with a larger available workforce or workspace. Reducing onsite density of workers may provide productivity improvement opportunities.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3.3 Local, regional, or national labor availability	Prework can relocate work away from adverse local, regional or national labor situations.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3.4 Availability of skilled labor	Prework can move critical work to locations where adequate skilled labor is available.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3.5 Project-specific requirements such as licenses for craft workers	On projects with a lack of required licensed craft workers, prework may provide an economic alternative to bringing licensed workers to the site.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3.6 Labor agreements or jurisdictional issues	Labor agreements or jurisdictional issues may limit the amount of work transferred offsite. Pre-work may be restricted or uneconomical based upon local tax incentives, pre-existing conditions requiring the use of local labor, craft labor agreements or others.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3.7 Sufficiency of labor in a multiple project environment	Given a company with multiple projects drawing from one labor pool, prework may help to alleviate labor strains on other company projects.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3.8 Stability of labor cost	Work can be relocated through prework to areas with less labor volatility.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3.9 Local/Regional political considerations	Percent of work guaranteed to local labor to secure favorable political support or for tax relief.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3.10 Multiple shifts of construction workers	Onsite labor requiring multiple shifts may be relocated offsite through prework to reduce productivity decreases due to shift work.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Please click on the right arrow and move to the next category of detailed questions.		<input type="button" value="Previous"/>	<input type="button" value="Next"/>	Final Score	Average Row Score	Incomplete	

CATEGORY 4 – SAFETY

CII Strategic Decision Tool for PPMOF (Prefabrication, Preassembly, Modularization, and Off-site Fabrication)									
Detailed Questions of Strategic Level II Evaluation									
4. Safety		To what extent could the following safety-related issues be desirable for traditional field erection (negative value) or desirable for PPMOF (positive value) for the project under consideration?					Home ↑ ↓		
Factor	Description	N/A	Pro Field Erection -5	-2	Neutral 0	+2	Pro PPMOF +5		
4.1 Unusual site or regional hazards	Offsite work can minimize necessary work in hazardous areas and reduce costs for protecting workers during traditional work methods.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>		
4.2 Ongoing facility operations	Reducing in the number of workers and types of crafts may reduce impacts on any ongoing operations.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>		
4.3 On-site labor density	Reducing in the number of workers and types of crafts may reduce exposure to hazards.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>		
4.4 Increased risk from high elevations, confined spaces, known toxic atmospheres, etc.	Prework may reduce worker exposure in areas such as high elevations, wet or slippery environments, or trenches. The use of prework has the potential to bring a larger portion of work to a controlled environment at ground level.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>		
4.5 Contractual monetary incentives for a better project safety record	Reduced hazard exposure through prework may provide greater opportunity for monetary incentives associated with safety.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>		
4.6 Reductions in insurance costs	Reduction in exposure through prework may justify reduction in insurance costs.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>		
4.7 Heavy lifts	Prework may involve larger lifts, requiring further safety planning.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>		
4.8 Regulatory requirements	Safety regulatory requirements for onsite personnel may be reduced if work is relocated to areas with fewer requirements.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>		
Please click on the right arrow and move to the next category of detailed questions.		← →		Final Score		Average Row Score		Incomplete	

CATEGORY 5 – SITE ATTRIBUTES

CII Strategic Decision Tool for PPMOF (Prefabrication, Preassembly, Modularization, and Off-site Fabrication)							
Detailed Questions of Strategic Level II Evaluation							
5. Site Attributes		To what extent could the following issues related to site attributes be desirable for traditional field erection (negative value) or desirable for PPMOF (positive value) for the project under consideration?				Home	
Factor	Description	N/A	Pro Field Erection -5 -2	Neutral 0	Pro PPMOF +2 +5		
5.1	Anticipated weather conditions at the site	Prework can be done at remote locations where the weather is more predictable or controlled.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5.2	Political issues	Prework can be relocated to areas with more favorable political climates.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5.3	Environmental restrictions	Prework can move some work off plot or offsite where traditional methods would require additional considerations due to environmental restrictions.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5.4	Local infrastructure to support the project	Prework can relocate activities to locations where there is adequate infrastructure such as supplies, vendors, housing or hotels, and power supply.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5.5	Rights-of-way and property boundaries	The site must be checked for any areas that might restrict the transport of prework into the installation area.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5.6	Laydown and staging space on the site	Prework such as preassembly requires additional space for assembly and preparation for installation.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5.7	Access onto and on site	Space must be allotted for erection and installation equipment required for prework.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5.8	Remote locations with minimal infrastructure	Prework can reduce the need for establishing site infrastructure by reducing the size and duration of onsite labor.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Please click on the right arrow and move to the next category of detailed questions.		<input type="button" value="Previous"/> <input type="button" value="Next"/>	Final Score	Average Row Score	Incomplete		





CATEGORY 6 – MECHANICAL SYSTEMS

CII Strategic Decision Tool for PPMOF (Prefabrication, Preassembly, Modularization, and Off-site Fabrication)						
Detailed Questions of Strategic Level II Evaluation						
6. Mechanical Systems		to what extent could the following issues related to mechanical systems be desirable for traditional field erection (negative value) or desirable for PPMOF (positive value) for the project under consideration?				Home
Factor	Description	N/A	Pro Field Erection -5 -2	Neutral 0	Pro PPMOF +2 +5	
6.1 Mechanical system density (amount of installed items in a given space)	Efficiencies in layout and quality control may be realized through prework of piping intense projects.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6.2 Grouping or arrangement of mechanical systems	Grouping equipment into preassemblies or modules may provide advantages for construction efficiency or maintainability.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6.3 Maintenance requirements for the facility	Prework design can take into account maintenance requirements provided information is made available at the time of design.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6.4 Size of equipment of assembly	Equipment sizes of less than 14 feet provide opportunities to maximize advantages of prework while fitting most shipping envelopes. Projects with larger equipment may still benefit from partial prework.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6.5 Special material assembly methods (alloy welding, etc.)	Shop conditions provided by some forms of prework.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6.6 Special assembly requirements such as "clean room" conditions	Some sensitive equipment can be preassembled and verified in a controlled environment, reducing risks of damage or exposure.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6.7 Electrical system density	Prework designs can help consolidate high-density electrical systems.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6.8 Electrical system routing requirements	Extensive routing requirements may require additional design for cross module wiring, increases design costs and fit up requirements.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Please click on the right arrow and move to the next category of detailed questions.			Final Score	Average Row Score	Incomplete	





CATEGORY 7 – PROJECT AND CONTRACT TYPES

CII Strategic Decision Tool for PPMOF (Prefabrication, Preassembly, Modularization, and Off-site Fabrication)							
Detailed Questions of Strategic Level II Evaluation							
7. Project and Contract Types		To what extent could the following issues related to project/contract types be desirable for traditional field erection (negative value) or desirable for PPMOF (positive value) for the project under consideration?				Home	
Factor	Description	N/A	Pro Field Erect	Neutral	Pro PPMOF		
			-5	-2	0	+2	+5
7.1	Replication on other projects	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
7.2	Protection of proprietary technology or methods	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
7.3	Project goals that include financial incentives	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
7.4	Supplier/contractor flexibility to provide a facility that meets owner's performance requirements	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Please click on the right arrow and move to the next category of detailed questions.				Final Score	Average Row Score	Incomplete	

CATEGORY 8 – DESIGN

CII Strategic Decision Tool for PPMOF (Prefabrication, Preassembly, Modularization, and Off-site Fabrication)									
Detailed Questions of Strategic Level II Evaluation									
8. Design		To what extent could the following design related issues be desirable for traditional field erection (negative value) or desirable for PPMOF (positive value) for the project under consideration?					Home  		
Factor	Description	N/A	Pro Field Erection -5	-2	Neutral 0	+2	Pro PPMOF +5		
8.1	Availability of key project team members in early stages of the project development	Prework requires early involvement of many parties, including client, designer, and construction representatives.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	
8.2	Requirement for early "freezing" of design	Many types of offsite prework require a certain level of design freeze prior to fabrication in order to meet transportation requirements.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	
8.3	Project and/or Owner's organizational structure	Inexperienced or uninformed project participants may require briefing on prework characteristics, benefits and requirements.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	
8.4	Availability of 3D CAD or similar design technology	Some complex designs for prework benefit from the ability to design with 3D CAD.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	
8.5	Infrastructure (hardware & software) for communications	Increased coordination and information exchange required for prework can benefit from internet connections between participants.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	
8.6	Software compatibility for design and for communication	Communicating between multiple work sites such as fabrication shops may require upgrades in design and communication technology to insure compatibility.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	
8.7	Flexibility accommodating modifications or expansion	Prework elements can be designed for duplication or expansion. Prework can also be designed for easy modification providing plant or manufacturing flexibility.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	
Please click on the right arrow and move to the next category of detailed questions.					Final Score	Average Row Score	Incomplete		

CATEGORY 9 – TRANSPORTATION & LIFTING REQUIREMENTS

CII Strategic Decision Tool for PPMOF (Prefabrication, Preassembly, Modularization, and Off-site Fabrication)								
Detailed Questions of Strategic Level II Evaluation								
9. Transportation and Lifting Requirements		To what extent could the following transportation/lifting requirements related issues be desirable for traditional field erection (negative value) or desirable for PPMOF (positive value) for the project under consideration?					Home  	
Factor	Description	N/A	Pro PPMOF					
			-5	-2	0	+2	+5	
9.1	Availability of transportation methods	Adequate truck, rail or barge transporters will be required depending on the size and weight of prework elements.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
9.2	Local transportation costs	Prework shipping may involve fees or other costs associated with location or transportation route.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
9.3	Transportation infrastructure	Transportation routes must be evaluated to handle the proposed shipments (road and bridge height and weight restrictions).	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
9.4	Permitting	Some areas require permits for loads of certain sizes and weights. Permits must be obtained to make transport feasible.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
9.5	Risks of loss during transportation	Prework may include larger assemblies and increase the value of single shipments.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
9.6	Impacts of weather conditions	Weather conditions may dictate prework shipping windows or transportation methods.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
9.7	Insurance and warranties during transport	Large prework shipments may carry significantly higher insurance coverage. Supplier warranties for prework must also be considered.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
9.8	Availability of lifting and hauling equipment	Prework may reduce the duration of equipment on site. However, larger or heavier assemblies may require additional equipment support during installation. Site location and availability of equipment may affect scope of prework.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
9.9	Foundations required for prework items	Prework may require fewer or greater foundations than conventional methods, depending on the type and scope of the work.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
9.10	Heavy lifts and related planning	Large complex prework may require additional planning for heavy or oversized lifts.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Please click on the right arrow and move to the next category of detailed questions.					Final Score	Average Row Score	Incomplete	

CATEGORY 10 – SUPPLIER CAPABILITY

CII Strategic Decision Tool for PPMOF (Prefabrication, Preassembly, Modularization, and Off-site Fabrication)									
Detailed Questions of Strategic Level II Evaluation									
10. Supplier Capability		To what extent could the following issues related to supplier capability be desirable for traditional field erection (negative value) or desirable for PPMOF (positive value) for the project under consideration?					Home ↑ ↓		
Factor	Description	N/A	Pro Field Erection		Neutral		Pro PPMOF		
			-5	-2	0	+2	+5		
10.1 Supplier availability	Supplier availability may affect lead times on deliverables (while on-site component supplier's delivery problems could drive pre-work, pre-work supplier delivery problems could be an impediment).	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
10.2 Availability of qualified suppliers	Prework suppliers requirements may include certain certifications or levels of quality.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
10.3 Supplier shop capacity	Production, experience and quality characteristics of a supplier may dictate the scope of prework.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
10.4 Level of sophistication of supplier's information systems	Prework projects generally require increased coordination and communication between project participants. The use of electronic file transfer, email, 3D CAD and other electronic resources may be requirements for certain types of prework.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
10.5 Supplier's availability of on-site representation	Supplier representation may be required during installation, inspection or other aspects of the project.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
This is the last category of detailed questions. Please click on the "Final Score." ← → Final Score									
								Average Row Score	Incomplete

Appendix B: Research Team Members and Affiliations

CII PT 171 PPMOF Research Team:

A. Scott Flatley, BE&K, Inc.
Carl T. Haas, The University of Texas at Austin
B. J. Lewis, Chicago Bridge & Iron Company
M. Richard Mayes, Rust International Corporation
Robert J. McCabe, U. S. Steel
Robert A. Smith, Lockwood Greene E&C
Wayne Sykes, Kvaerner Process
Clyde B. Tatum, Stanford University
Jorge A. Vanegas, Georgia Institute of Technology
Curtis R. Watson, Eichleay Engineers & Constructors, Inc.
Terry S. Wilford, U. S. Army Corps of Engineers
Paul Wood, Eli Lilly and Company
Daryl P. Zimmerman, U. S. Department of State

Past Membership:

Mike von Hirschberg, Jacobs Applied Technology
W. David Jacobs, Washington Group Int'l, Inc.
Karl Lemmenes, Lester Building Systems
Jonathan Maude, LTV Steel Company
Louis L. Prudhomme, Construction Industry Institute
Flo Sepulveda, Stone & Webster Engineers & Constructors

Appendix C: Beta Test Survey and Summary of Results

SURVEY COVER LETTER

To Whom It May Concern:

Subject: Beta Test for CII Strategic Decision Tool for PPMOF

On behalf of the Construction Industry Institute research project team 171, I appreciate your interest in beta testing a new product related to prefabrication, preassembly, modularization, and offsite fabrication (PPMOF).

Based on our decision-making framework for PPMOF, the research team has developed the product to facilitate the decision-making process. Attached are the documents and spreadsheet-based tool that make up the product. A draft Implementation Guidelines explains how to use the tool, and a draft Research *Summary provides some background.*

We have also attached a survey questionnaire in a spreadsheet form to solicit your feedback concerning the product's usefulness. Please complete the questions directly in the spreadsheet or in a print out form, and let us know if the decision tool could help lead you to make better decisions more consistently and easily.

In conjunction with this beta test, we are looking for an exemplary case for the use of the tool that could be presented at the CII Annual Conference this August. Thus, we would like to have your evaluation of feasibility of PPMOF for a specific project. We would appreciate having your resulting evaluation with the tool, in the form of a spreadsheet file. When through with the tool, you can save your results as any different name, but not as the same as given, since the original is read-only. Otherwise, you can also print out the questions of the tool in a written form, fill them out and copy to us.

Should you encounter any problem using the tool, please contact me or my research assistant, Jongchul Song, at uniastro@mail.utexas.edu.

Thank you.

Sincerely,

Carl T. Haas, Ph.D., P.E.
Liedtke Centennial Fellow and
Associate Professor in Civil Engineering
University of Texas at Austin

QUESTIONNAIRE FORM

Survey for Validation of Strategic Decision Tool for Prefabrication, Preassembly, Modularization, and Offsite Fabrication

Construction Industry Institute Research Project Team 171

Evaluation Date: _____

1 of 2

About the Project

1. What type of facility is being considered for PPMOF?

- | | |
|---|----------------------------------|
| _____ Electrical Generating | _____ Oil Production/Refining |
| _____ Chemical Mfg. | _____ Environmental |
| _____ Pharmaceuticals Mfg. | _____ Metals Processing/Refining |
| _____ Microelectronics Mfg. | _____ Natural Gas Processing |
| _____ Other (please briefly describe below) | |

2. In what stage is the project you are considering for PPMOF?

- | | |
|---------------------|--|
| _____ Completed | _____ Pre-Project Planning (Front End) |
| _____ Detail Design | _____ Procurement |
| _____ Construction | _____ Start-Up |

3. Where is this project located? (City, State, Country)

4. Under what type of contract is this project being executed?

- _____ Lump Sum (Single Fixed Price)
- _____ Cost Reimbursable (Unit Price)
- _____ Cost Plus a Fee (includes guaranteed maximum price)
- _____ Other

5. What is the approximate total cost of the entire project?

\$ _____

6. What is the total scheduled duration of this project

_____ months _____ Don't Know

7. How would you primarily characterize this project? (Check only one)

_____ Grass Roots _____ Revamp _____ Add-on

Grass roots : a new facility from the foundations and up. It includes a project requiring demolition of an existing facility before new construction begins

Revamp : a facility for which a substantial amount of the equipment, structure, or other components is replaced or modified, and which may expand capacity and/or improve the process or facility

Add-on : a new addition that ties in to an existing facility, often intended to expand capacity

8. What you think is the most important objective of this project?

(For example, cost and schedule)

9. How would you describe the level of complexity for this project as compared to other projects from the same industry sector?

_____ Low _____ Average _____ High

High complexity : characterized by the use of unproven technology, an unusually large number of process steps, large facility size or process capacity, new construction methods, etc.

10. What type of delivery methods is intended for this project?

_____ Construction/Project Management _____ Design-build (Turnkey)

_____ Traditional

**Survey for Validation of Strategic Decision Tool for
Prefabrication, Preassembly, Modularization, and Offsite Fabrication**

Construction Industry Institute Research Project Team 171

Evaluation Date: _____

2 of 2

About You and Your Company

1. What services has your company contracted to provide on this project? (Check all that apply)

_____ Design _____ Engineering
_____ Procurement _____ Construction

2. Please indicate the function(s) your company performed on this project. (Check all that apply)

_____ Project Manager _____ General/Prime Contractor
_____ Construction Manager _____ Subcontractor/Supplier

3. Please provide your company name. _____

4. Please provide your name, role/title for this project and contact?

Name _____ Role/Title _____
Phone No. _____ E-mail address _____

About the Tool

1. Is the tool useful?

_____ | _____ | _____ | _____ | _____
Strongly Disagree Disagree Neutral Agree Strongly Agree

2. Is it easy to use?

_____ | _____ | _____ | _____ | _____
Strongly Disagree Disagree Neutral Agree Strongly Agree

3. Did it help you in the decision-making process on PPMOF?

_____ | _____ | _____ | _____ | _____
Strongly Disagree Disagree Neutral Agree Strongly Agree

4. Would it help you align your team?

_____ | _____ | _____ | _____ | _____
Strongly Disagree Disagree Neutral Agree Strongly Agree

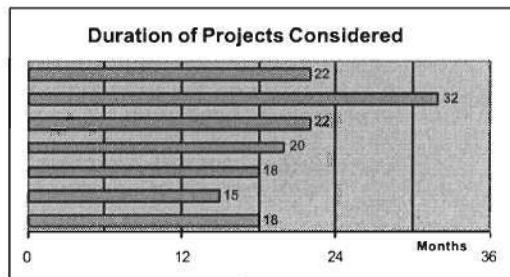
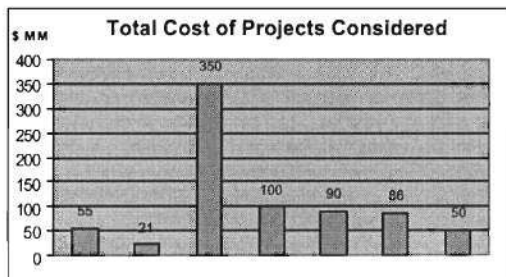
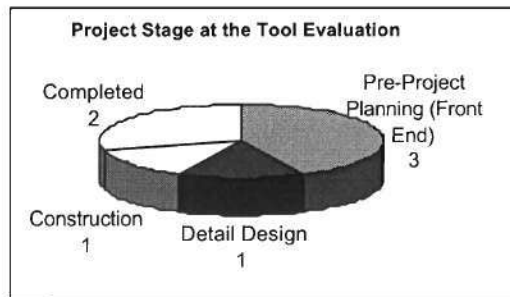
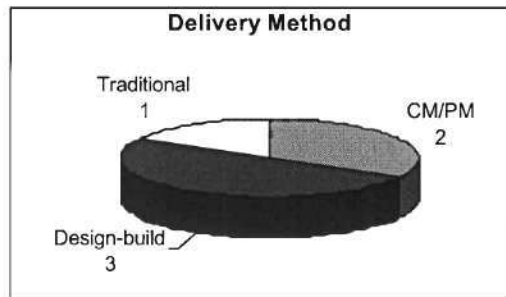
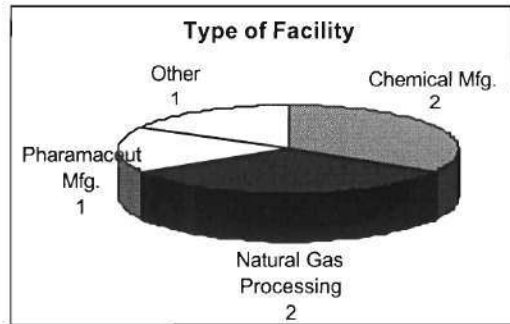
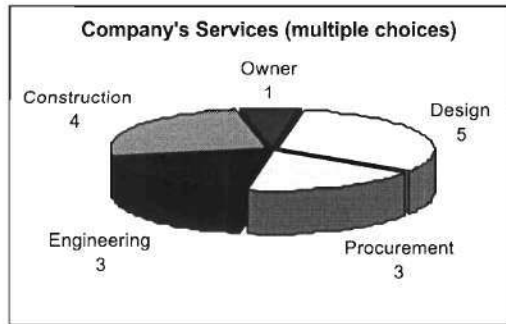
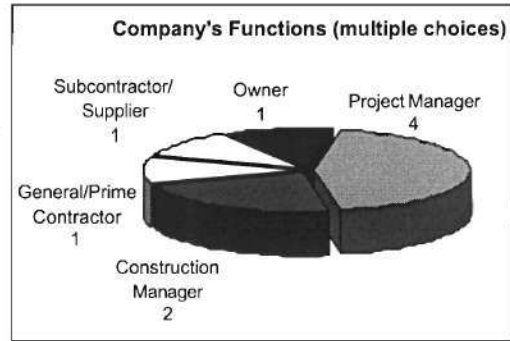
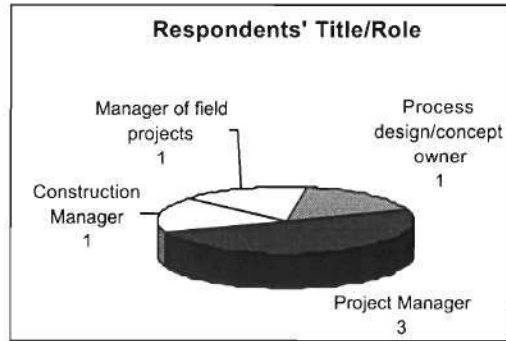
5. Would you recommend for purchase or use on future projects?

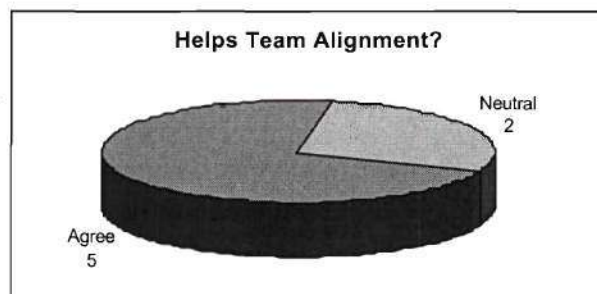
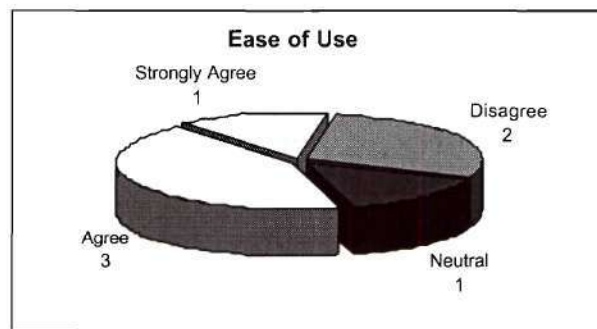
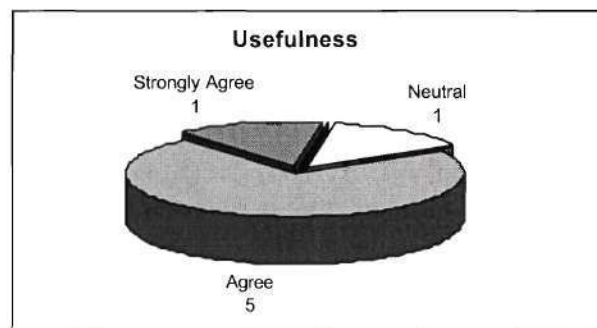
_____ Yes _____ No

6. Please provide any suggestions for future enhancements?

Thank you for answering questions.

SUMMARY OF RESULTS





References

- Adelman, L. (1992). *Evaluating Decision Support and Expert Systems*.
- Albright, S. C. (2001). *VBA for Modelers Developing Decision Support Systems with Microsoft® Excel*.
- Bidgoli, H. (1989). *Decision Support Systems Principles & Practice*.
- Burke, L. I. (1991). "Introduction to Artificial Neural Systems for Pattern Recognition." *Computing and Operations Research*. 18(2).
- CII (1992). *MODEX User's Guide*. Publication 29-1. Construction Industry Institute, The University of Texas at Austin.
- Cigolini, R. and Casteliano, A. (2002). "Using Modularization to Manage Construction of Onshore Process Plants: A Theoretical Approach and a Case Study." *Project Management Journal*. 33(2).
- Fagerlund, W. R. (2001). *Decision Framework for Prefabrication, Pre-assembly and Modularization in Industrial Construction*. M.S. Thesis. The University of Texas at Austin.
- Fisher, D. J., and Skibniewski, M. (1992). "Computerized Decision Support for Modularization of Industrial Construction." SD-72. Construction Industry Institute, The University of Texas at Austin.
- Haas, C. T., O'Connor, J. T., Tucker, R. T., Eickmann, J. A., and Fagerlund, W. R. (2000). *Prefabrication and Preassembly Trends and Effects on the Construction Workforce*. Report No. 14. Center for Construction Industry Studies, The University of Texas at Austin.
- Hipel, K. W., Kilgour, M., Fang, L., and Peng, X. (2001). "Strategic Decision Support for the Services Industry." *IEEE Transactions on Engineering Management*. 48(3).
- Kamarthi, S. V., Sanvido, V. E., and Kumara, S. R. T. (1992). "Neuroform – Neural Network System for Vertical Formwork Selection." *Journal of Computing in Civil Engineering*. 6(2).

- Moselhi, O., Hegazy, T., Fazio, P. (1991). "Neural Networks As Tools in Construction." *Journal of Construction Engineering and Management*. 117(4).
- Murtaza, M., Fisher, D. J., and Skibniewski, M. (1993). "Knowledge-Based Approach to Modular Construction Decision Support." *Journal of Construction Engineering and Management*. 119(1).
- Murtaza, M. and Fisher, D. J. (1994). "Neuromodex – Neural Network System for Modular Construction Decision Making." *Journal of Computing in Civil Engineering*. 8(2).
- Tatum, C. B., Vanegas, J. A., and Williams, J. M. (1987). "Constructability Improvement Using Prefabrication, Preassembly, and Modularization." SD-25. Construction Industry Institute, The University of Texas at Austin.
- Taha, M. A., Abou-Zeid, A. M., Hanna, A. S., and Russel, J. S. (1998). "Merging Genetic Algorithms with Neural Networks: Owner-Contractor Prequalification Example." *Artificial Neural Networks For Civil Engineers: Advanced Features and Applications*.